AD NUMBER

AD 491 184

CLASSIFICATION CHANGES

TO **UNCLASSIFIED**

FROM **CONFIDENTIAL**

AUTHORITY

USNOL ltr; August 29, 1974.

19990303171

AD NUMBER

AD-491 184

NEW LIMITATION CHANGE

TO

DISTRIBUTION STATEMENT - A

Approved for public release; distribution is unlimited.

LIMITATION CODE: 1

FROM

No Prior DoD Distr Scty Cntrl St'mt

AUTHORITY

DoDD 5230.24, para f.3.b.; August 29, 1974.

AD-491 184

NAVORD REPORT 4053

WIND-TUNNEL INVESTIGATION OF VARIOUS CONFIGURATIONAL MODIFICATIONS OF THE LOW-DRAG BOMB (U)

22 JULY 1958

U. S. NAVAL ORDNANCE LABORATORY

WHITE OAK, MARYLAND

[redacted]
NAVORD Report 4053

Aeroballistic Research Report 295

WIND-TUNNEL INVESTIGATION OF VARIOUS CONFIGURATIONAL MODIFICATIONS OF THE LOW-DRAG BOMB

Prepared by:

Fred J. DeMeritte
Harry Gauzza

~~ABSTRACT: This report presents~~ the results of an investigation in the NOL 40 x 40 cm Aeroballistics Tunnel No. 1 to study the static stability and drag of the low-drag bomb at subsonic and supersonic speeds. The following tests were made:

(a) Study of configurational changes designed to reduce the yaw of the bomb,

(b) Drag of the 250-pound bomb with supporting lugs (Mk-81 bomb),

(c) Stability of an 8-fin bomb with reduced fin span to improve the ground clearance problem.

U. S. NAVAL ORDNANCE LABORATORY
WHITE OAK, MARYLAND

[redacted]

NAVORD Report 4053 22 July 1958

This investigation was performed at the request of the Bureau of Ordnance (reference (a)) under Task Number A3d-453-1-56. The report covers recent wind-tunnel tests in the NOL 40 x 40 cm Aeroballistics Tunnel No. 1. Additional work has been done in the NOL firing ranges, the National Bureau of Standards wind-tunnel, and the Cornell transonic wind-tunnel under the direction of the NOL staff.

Previous NOL reports on the aerodynamics of the low-drag series can be found in references (b) through (f).

MELL A. PETERSON
Captain, USN
Commander

R. KENNETH LOBB
By direction

CONTENTS

ILLUSTRATIONS

WIND TUNNEL INVESTIGATION OF VARIOUS CONFIGURATIONAL MODIFICATIONS OF THE LOW-DRAG BOMB

INTORDUCTION

1. This report describes investigations carried out on a series of low-drag bombs of the U. S. Navy, in the wind-tunnels at the Naval Ordnance Laboratory. These bombs have a shape developed by Douglas Aircraft. The four low-drag bombs of this series are the 250 pound bomb, Mk 81; the 500 pound bomb, Mk 82; the 1000 pound bomb, Mk 83; and the 2000 pound bomb, Mk 84.

2. The tests made involved:

a. An investigation of the configurational changes to reduce the induced yawing moment and rolling moment of the bomb and improve the dynamic characteristics.

b. Drag of the 250 pound bomb with suspension lugs.

c. Investigation of the stability of configuration with fin span equal to the maximum body diameter.

3. The low-drag bomb with two-degree fin cant is believed to be one of the best bombs developed. The erratic flight mentioned in this report applies to only a small percentage of the bombs dropped.

Symbols

A	area (maximum) of the body (sq. in.)
C.G.	center of gravity (42.5 per cent length from the nose)
C_{D_o}	drag coefficient at zero angle of attack $\left(\frac{F_D}{qA}\right)$
C_D	drag coefficient $\left(\frac{F_D}{qA}\right)$
C_N	normal force coefficient $\left(\frac{F_N}{qA}\right)$
C_y	side force coefficient $\left(\frac{F_y}{qA}\right)$
C_ϕ	rolling moment coefficient $\left(\frac{M_\phi}{qAd}\right)$
C_ψ	yawing moment coefficient $\frac{M_\psi}{qAd}$

C_θ — pitching moment coefficient ($(\frac{M_\theta}{qAd})$ referred to C.G.)

d — model diameter (1.499 in.)

F_D — drag (lb)

F_N — normal force (lb)

F_y — side force (lb)

l — model length (see model sketches)

M_θ — pitching moment (in/lb)

M — yawing moment (in/lb)

M_ϕ — rolling moment (in/lb)

q — dynamic pressure (psi) see Table 1

Re — Reynolds number (based on model length) (see Table 1)

— angle of attack (deg.)

Discussion

4. The study of configurational changes of the low-drag bomb was a result of recurring indications of instability of the bomb during drops.

5. Early in the drop tests of the bombs it became obvious that the bomb was yawing badly. It appeared probable that the pitch frequency and the roll frequency were becoming equal at about one cycle per second and that the bomb was locking into resonance. Initially the fin cant was zero degree with a manufacturing tolerance of ± 0.5 degree. Calculation showed that accidental fin cant within this tolerance could produce sufficient roll to cause resonance. Hence it was decided to cant the fins two degrees and thus produce a roll which would be too large to result in resonance. This change appeared to cure the trouble with the low-drag bombs.

6. Several years later, however, during dive-bombing tests, large yaw reappeared in a few of the drops. Figures 26 and 27 present the yaw history of a drop made at Chincoteague, Virginia. The figures show the bomb beginning to damp then undamp and later damp again. The key to the problem appears to be the roll-lock-in. The roll history shows that the roll rate of the bomb increases from zero to about one cycle per second, then "locks in" and the bomb continues to roll uniformly. While rolling at this rate the bomb is in a reasonance condition. The yaw increases until a large angle is reached. Wind-tunnel tests at the National Bureau of Standards show that large rolling moments are present at large angles of attack. These large

moments cause increase in roll rate, breaking out of resonance, and an approach to a steady state rolling frequency of 7 to 10 cycles per second. While the roll rate is increasing the yaw decreases rapidly and the bomb falls satisfactorily.

7. The condition for roll-lock-in is

$$L + L_p + L = 0$$

where;

L = Rolling moment due to fin cant

L_p = Roll damping moment

L = Induced rolling moment

Wind-tunnel tests show that the induced rolling moment causes the roll-lock-in. Possible cures for roll-lock-in appear to be

a. reduce the induced rolling moment
b. increase the fin span

When roll-lock-in occurs, the low drag bomb experiences what is known as "Catastrophic Growth of Yaw" at resonance due to yawing moment. To cure this:

a. reduce yawing moment
b. increase fin span
c. increase damping moment
d. reduce nutation arm

When it was first learned that the bomb was yawing badly, studies were made to determine if the trouble was resonance or Magnus instability. Calculation of the damping rate of the precessional and nutational arms showed that the present bomb was probably not experiencing Magnus instability, but if the steady state rolling velocity was increased by more fin cant, Magnus instability could occur. Therefore, increasing fin cant in hopes of preventing "lock-in" did not appear feasible. Since the bomb experiences difficulty at large angles of attack, two methods appeared promising in preventing the erratic flight. One method was to increase the fin span and chord to increase the pitch damping and the other method was to investigate fin shapes which have low induced rolling moments and low yawing moments.

Induced Roll Program and Large Fin Program

8. The following configurations were reported in this test program. Other configurations are reported in references e and f.

(a)	basic low-drag bomb (no fin cant)	Figures 1,24
(b)	2 degree fin cant	Figure 2
(c)	1.66 d span tail	Figure 4
(d)	2.05 d span tail	Figures 5,6
(e)	large nose vanes	Figures 7,9
(f)	small nose vanes	Figures 8,9
(g)	1.66 d d span (tail moved rearward 0.233 inches)	Figures 3,4
(h)	end plate	Figures 13,17
(i)	box shroud	Figures 15,17
(j)	1/2 box shroud	Figures 16,17
(k)	porous box shroud	Figures 14,17
(l)	6 fin model	Figures 12,17
(m)	long chord (1.4 d span and chord of 2.05 d span model)	Figures 10,11
(n)	body alone	Figure 18

9. The configurations were all tested at a Mach number of 0.91 or 0.95 at a fin roll orientation of 22.5 degrees. In addition some configurations were tested at fin orientations of zero degree and 45 degrees and at Mach numbers of 0.80 and 1.57 or 1.58. Figures 61, 62, and 63 show, in barograph form, a comparison of the various configurations. It should be pointed out that the nose vanes were placed in such a position, due to model construction, that a loss of stability resulted. If the vanes had been placed on the center of gravity or aft of the center of gravity this would not have occurred. The porous box shroud was selected as a configuration because it was believed that the solid box shroud would be unstable at transonic and supersonic Mach numbers. However, the solid box shroud configuration was stable at the Mach numbers tested. Photographs and sketches of all the models are shown in Figures 1 through 18. Figures 20 through 55 are plots of normal force, pitching moment, rolling moment, side force and yawing moment versus angle of attack.

10. The effects of the induced rolling moment were investigated by free-spin tests at the National Bureau of Standards on a number of modifications to the fins such as twist, tangent, sweep and at the Naval Ordnance Laboratory using configurations which are altered more radically (ref. f).

Reduced Fin Span Program

11. There has been some interest in reducing the fin span of the low drag bomb. This would aid the ground and airplane clearance problems. Tests were made (reference (d)) of an eight-fin bomb with a fin span of one diameter. The configuration was unstable. Later an attempt was made to stabilize the configuration using one-half and one-diameter chord shrouds. Photographs and sketches of the configurations are shown in Figures 19 through 22. The shrouds stabilized the bomb at the supersonic speeds but at the transonic speeds the bomb was still unstable. Figures 56 and 57 show the data obtained for these configurations.

Effect of Lugs Program

12. Tests were made of the Mk 81 (250 pound bomb) with mounting lugs. The stability data for the lug configuration are shown in Figures 58 and 59. Note that this lug seems to cause a very slight change in trim as would be expected. The drag coefficient was greatly increased as can be seen in Figure 60. The drag coefficient with lugs compared favorably with free-flight drop data obtained informally from the Bureau of Ordnance. Photographs and sketches of this configuration are shown in Figures 23 and 24.

Models, Balances, and Data Reduction

13. All the models and balances were designed and manufactured by the Naval Ordnance Laboratory. The models were manufactured of steel and are shown in photographs and sketches in Figures 1 through 24. The data were obtained using a six-component strain-gage balance (5-16) (see reference (g)).

14. The data were recorded using the automatic data recording system explained in reference (h). The raw data are recorded into IBM cards and the data are then reduced to coefficient form by IBM machines using the data reduction equations given in reference (i).

15. Test conditions are given in Table 1. All angles of attack were corrected for the static deflection of the balance sting due to the aerodynamic loads. An index of the plotted data is presented in Table 2. The NOL sign convention is shown in Figure 25.

Conclusions

16. Figures 61, 62, and 63 show the effect of configuration changes on the pitching moment, yawing moment, and induced rolling moment at a Mach number of approximately 0.9 and Mach number 1.7. The configurations with large increases in pitch moment or large decreases in the induced rolling moment and yawing moment are configurations which should perform more reliability than the basic low drag bomb.

17. This report is intended as a progress report on the work done on the low-drag bomb in the NOL wind tunnels. Work is continuing in the NOL wind tunnel on the induced rolling moment problem and tests are being made by NOL personnel at the National Bureau of Standards to study the induced rolling moment, and at Cornell Aeronautical Laboratory to determine the transonic aerodynamics of the existing bomb, and firings are being made in the NOL firing range to obtain more information on the low-drag bomb.

References

(a) Griffin, T. R., "Wind-Tunnel Request" (WTR 286) (Conf.) 1955
(b) Gauzza, H. J., "Aeroballistic Investigation of the EX-10 Bomb at Subsonic Speeds," NAVORD Report 2814 (Conf.) 1953
(c) Long, J. E., "Free Flight Investigation of the Stability and Drag of the EX-10 General Purpose Bomb," NAVORD Report 2916 (Conf.)(1953)
(d) Long, J. E., "Low Yaw Data on the Low Drag Bomb (EX-10) at Transonic Speeds (0.? M 1.4)," NAVORD Report 4227 (Conf.) 1956
(e) Piper, W. D., "Static Stability Characteristics of the EX-10 Low Drag Bomb," NAVORD Report 4503 (Conf.) 1957
(f) DeMeritte, F. J., Gauzza, H., Shantz, I., "Miscellaneous Wind-Tunnel Tests on the Low Drag Bomb." NAVORD Report 5702, (Conf.) 1956
(g) Nicolaides, J. D., "On the Flight of Ballistic Missiles," BuOrd Ballistic Technical Note Number 1, 1950 (Conf.)
(h) Nicolaides, J D., and MacAllister, L. C., "A Review of Aeroballistic Range Research on Winged and/or Finned Missiles," BuOrd Ballistic Technical Note Number 5, 1954
(i) Nicolaides, J. D., "First Primer of Bomb Ballistics," BuOrd Technical Note 20 (Unclass.) 1955
(j) Shantz, I., Gilbert, B. D., and White, C. E., "NOL Wind-Tunnel Internal Strain-Gage Balance System," NAVORD Report 2972 (Unclass.) 1953
(k) Gilbert, B. D., "Automatic Data Processing System (ADAPS) For the Supersonic Wind-Tunnels," NAVORD Report 2813 (Unclass.) 1953
(l) DeMeritte, F. J., Gilbert, B. D., and White, C. E., "Contract Wind-Tunnel Testing," NAVORD Report 3562 (Unclass.)

TABLE 1
TEST CONDITIONS

MACH NO.	q psi	REYNOLDS NUMBER $\times 10^{-6}$
0.80	4.17	5.2
0.91	4.78	5.5
0.93	4.83	5.5
0.94	4.90	5.5
0.95	4.94	5.5
1.57	6.01	5.6
1.55	6.00	5.6

TABLE 2
INDEX TO PLOTTED DATA

CONFIGURATION	FIN POSITION DEGREES	MACH NO.	FIG. NO.
Body alone	---	0.8	28, 29
Basic	22.5	0.8	28, 29
2° fin cant	0	0.8	28, 29
2° fin cant	11.25	0.8	28, 29
2° fin cant	22.5	0.8	28, 29
2° fin cant	33.75	0.8	30, 31
2° fin cant	45	0.8	30, 31
1.667R d span	0	0.8	32, 33
1.667R d span	22.5	0.8	32, 33
Basic	22.5	0.8	32, 33
2° cant	22.5	0.95	34, 35
6 fin	22.5	0.95	34, 35
Large chord	22.5	0.91	34, 35
Basic	22.5	0.95	34, 35
1.667R d span	22.5	0.95	36, 37
1.667R d span	22.5	0.91	36, 37
2 d span	22.5	0.95	36, 37
Basic	22.5	0.95	36, 37
Porous box shroud	22.5	0.91	38, 39
Solid box shroud	22.5	0.91	38, 39
1/2 box shroud	22.5	0.91	38, 39
Basic	22.5	0.95	38, 39
End plate	22.5	0.91	40, 41
Large vane	22.5	0.95	40, 41
Small vane	22.5	0.95	40, 41
Basic	22.5	0.95	40, 41
End plate	0	0.91	42, 43
Basic	0	0.91	42, 43
1.667 d span	0	0.91	42, 43
Large chord	0	0.91	42, 43
Small vane	0	0.95	44, 45
Large vane	0	0.95	44, 45
Basic	0	0.91	44, 45

TABLE 2 (Cont'd)
INDEX TO PLOTTED DATA

CONFIGURATION	FIN ORIENTATION DEGREES	MACH NO.	FIG. NO.
6 Fin	0	0.95	46, 47
6 Fin	15	0.95	46, 47
Basic	0	0.91	46, 47
1/2 Box shroud	0	0.91	48, 49
Porous Box shroud	45	0.91	48, 49
Solid Box shroud	45	0.91	48, 49
Basic	0	0.91	48, 49
6 Fin	0	1.58	50, 51
2° cant	0	1.58	50, 51
Body alone	---	1.58	50, 51
Basic	22.5	1.57	52, 53
2° cant	22.5	1.58	52, 53
1.667R d span	22.5	1.57	52, 53
Porous Box	22.5	1.57	52, 53
Solid Box	22.5	1.57	52, 53
End Plate	22.5	1.57	54, 55
Basic	22.5	1.57	54, 55
6 Fin	15	1.58	54, 55
Small vane	22.5	1.58	54, 55
Large vane	22.5	1.58	54, 55
8 Fin, full shroud	0	0.94	56
8 Fin, half shroud	0	0.93	56
3 Fin	0	0.95	56
4 Fin	0	0.91	56
8 Fin, full shroud	0	1.58	57
8 Fin, half shroud	0	1.58	57
8 Fin	0	1.58	57
4 Fin	0	1.58	57
250# Bomb with Lug	0	0.94	58
250# Bomb without Lug	0	0.94	58
250# Bomb with Lug	0	1.58	59
250# Bomb without Lug	0	1.58	59

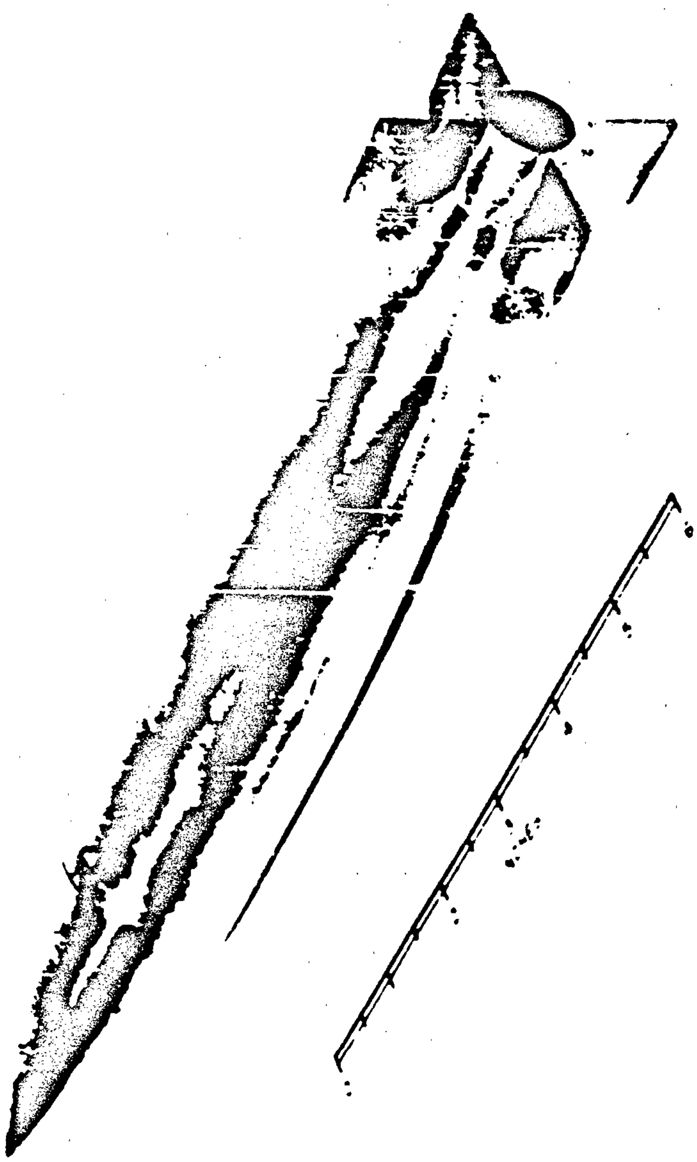


FIG. 1 BASIC MODEL (NO FIN CANT)

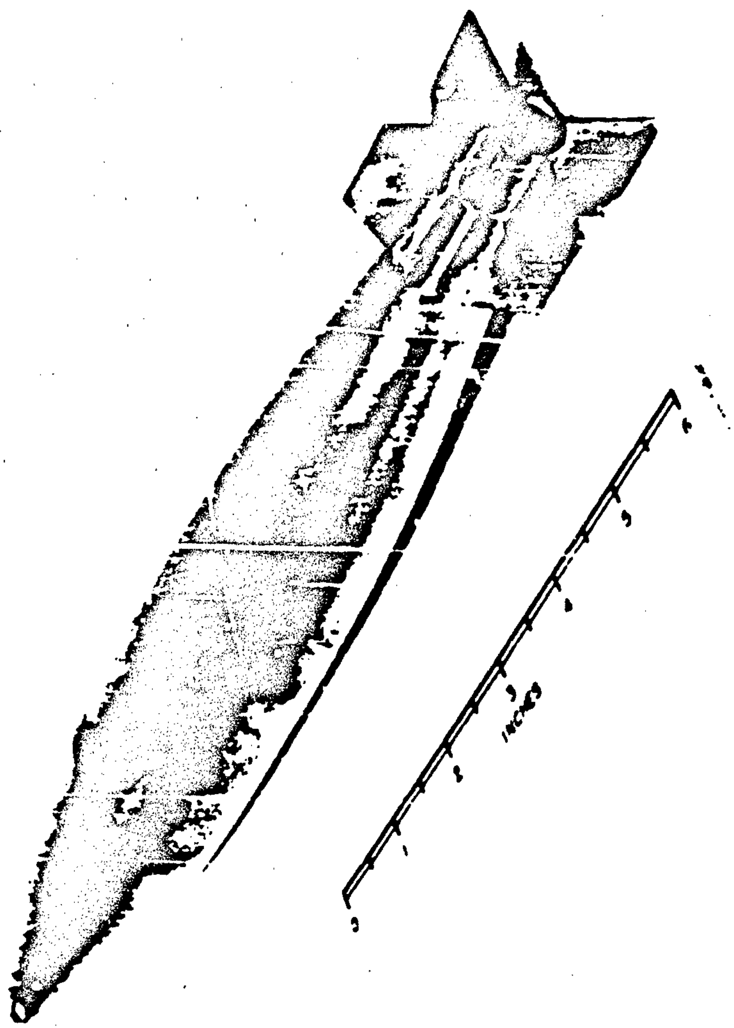


FIG. 2 BASIC MODEL (2-DEGREE FIN CANT)

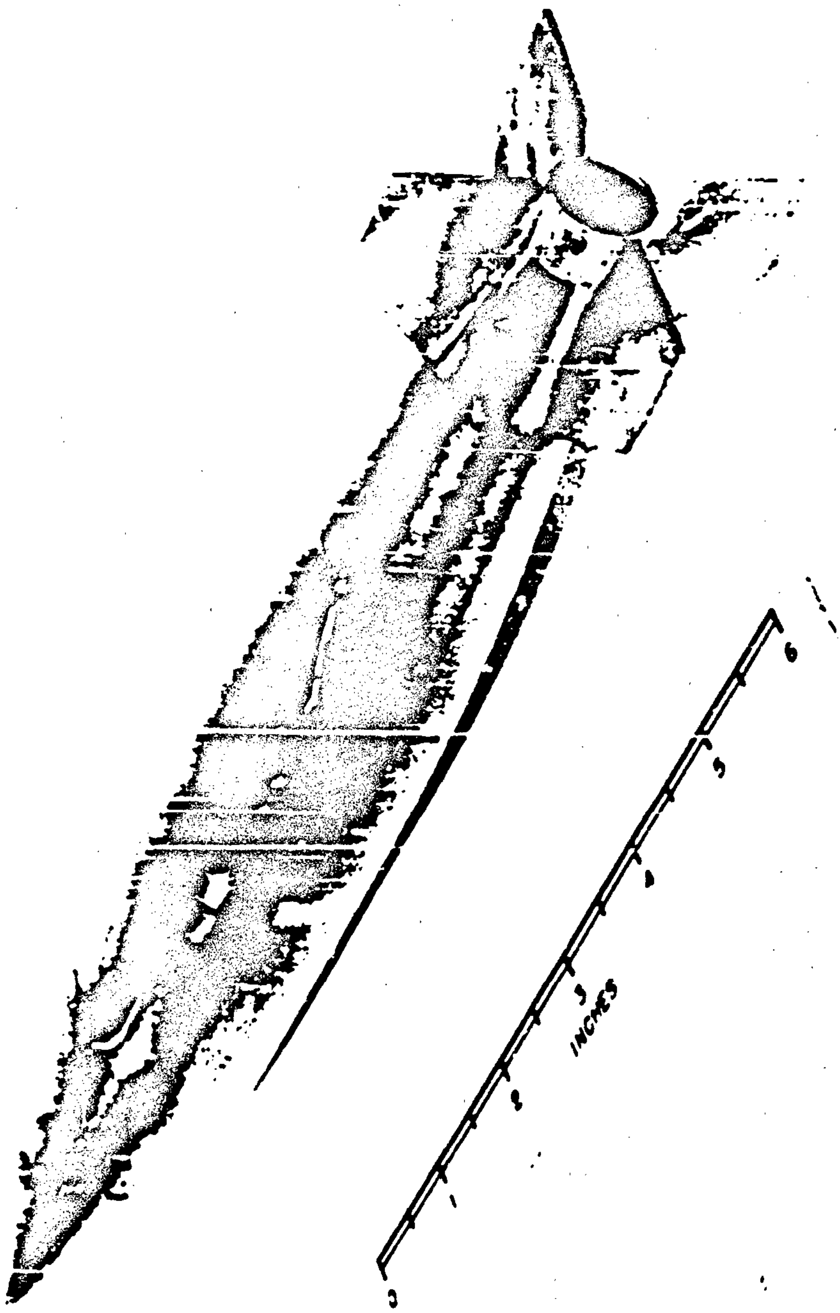


FIG. 3 1.667d FIN SPAN (REAR-POSITION) MODEL

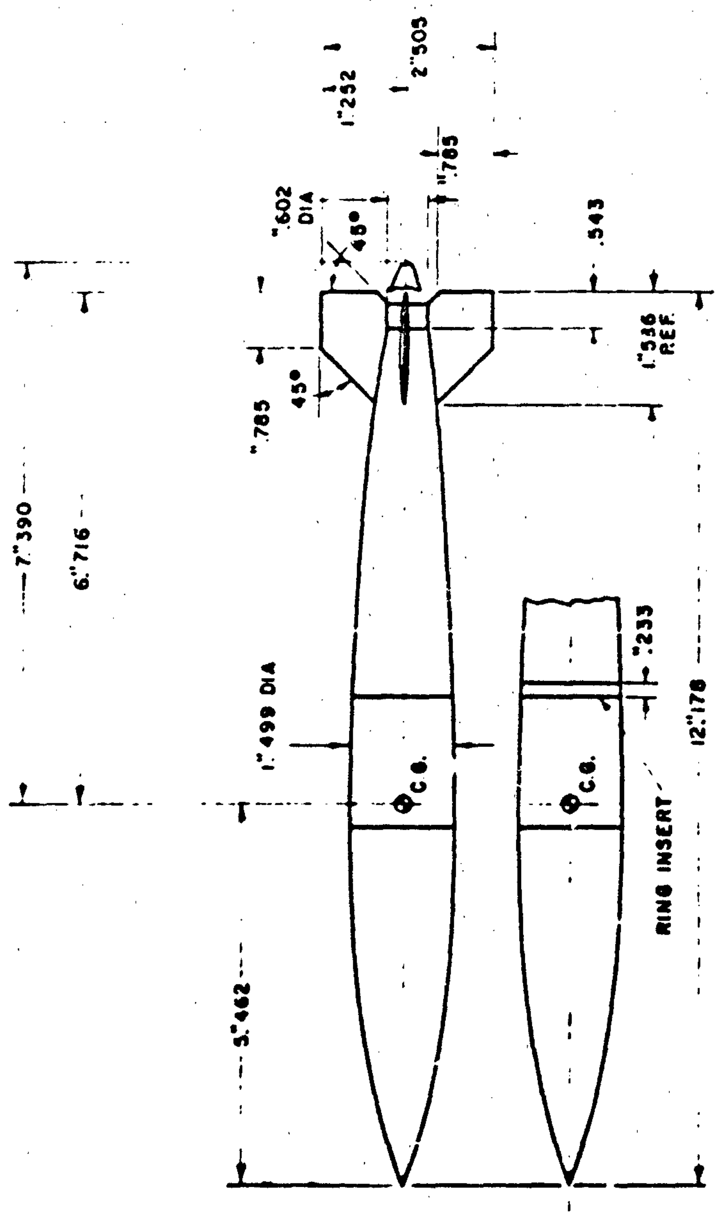


FIG. 4 1000 LB LOW DRAG BOMB
(4 FIN - 1.667 D SPAN)

CONFIDENTIAL
NAVORD REPORT 4053

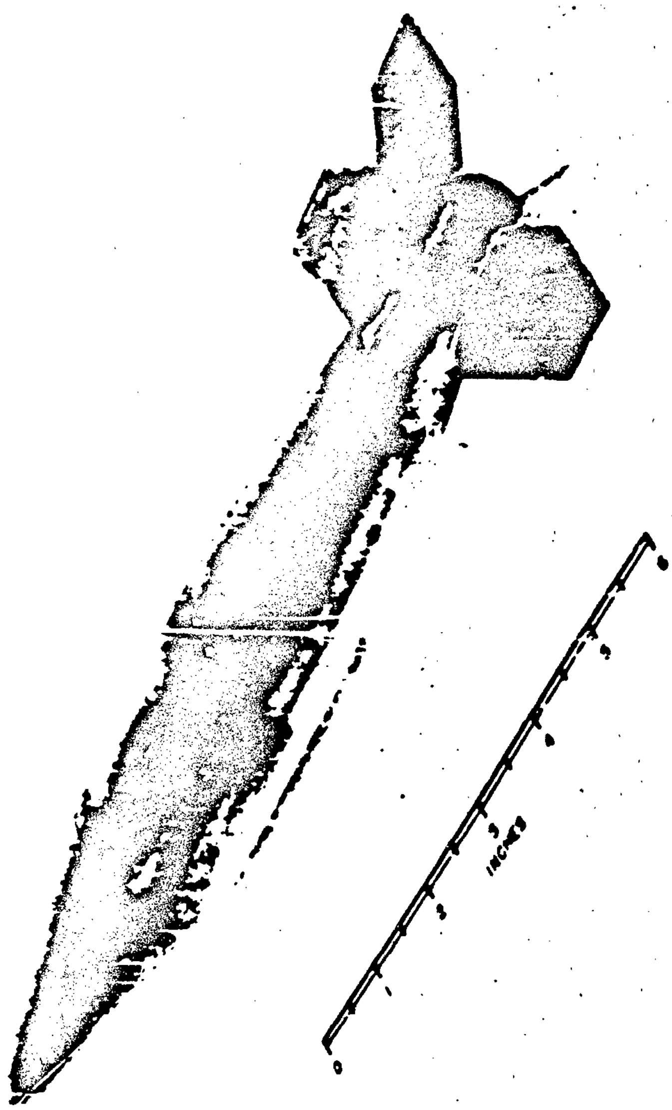


FIG. 5 2.05d FIN SPAN MODEL

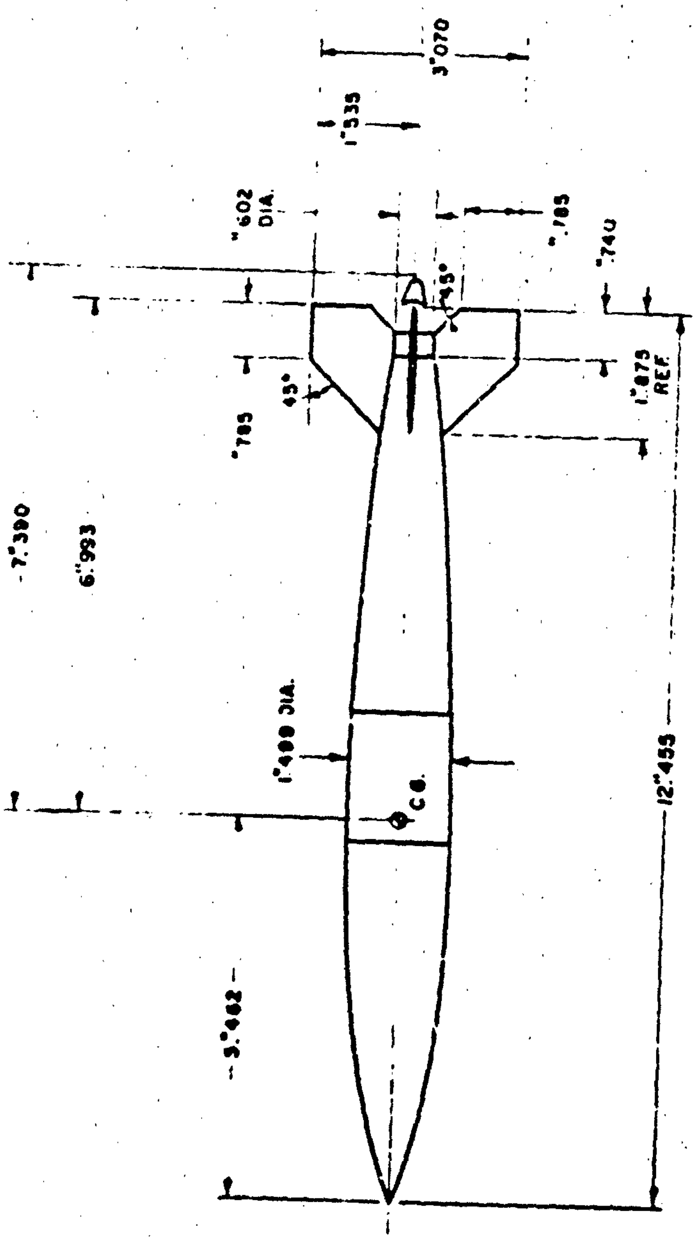


FIG. 6 1000 LB LOW DRAG BOMB
(4 FIN - 2.05 D SPAN)

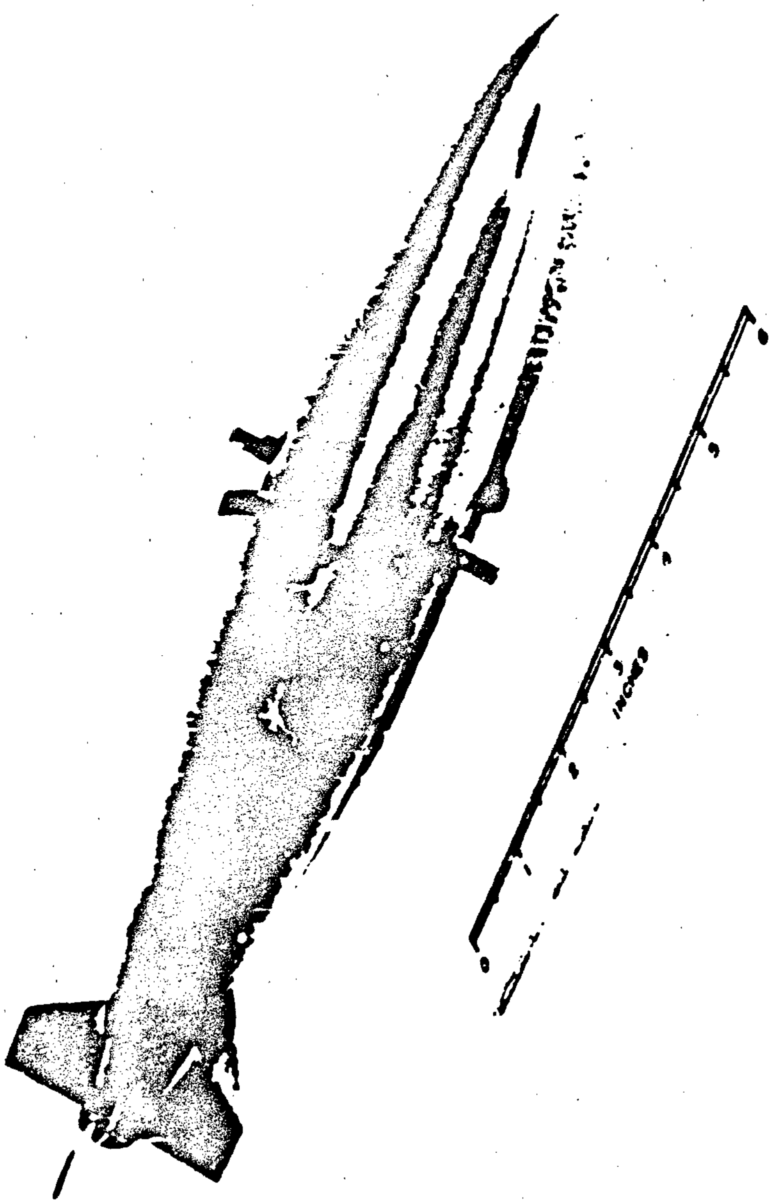


FIG. 7 LARGE NOSE VANES MODEL

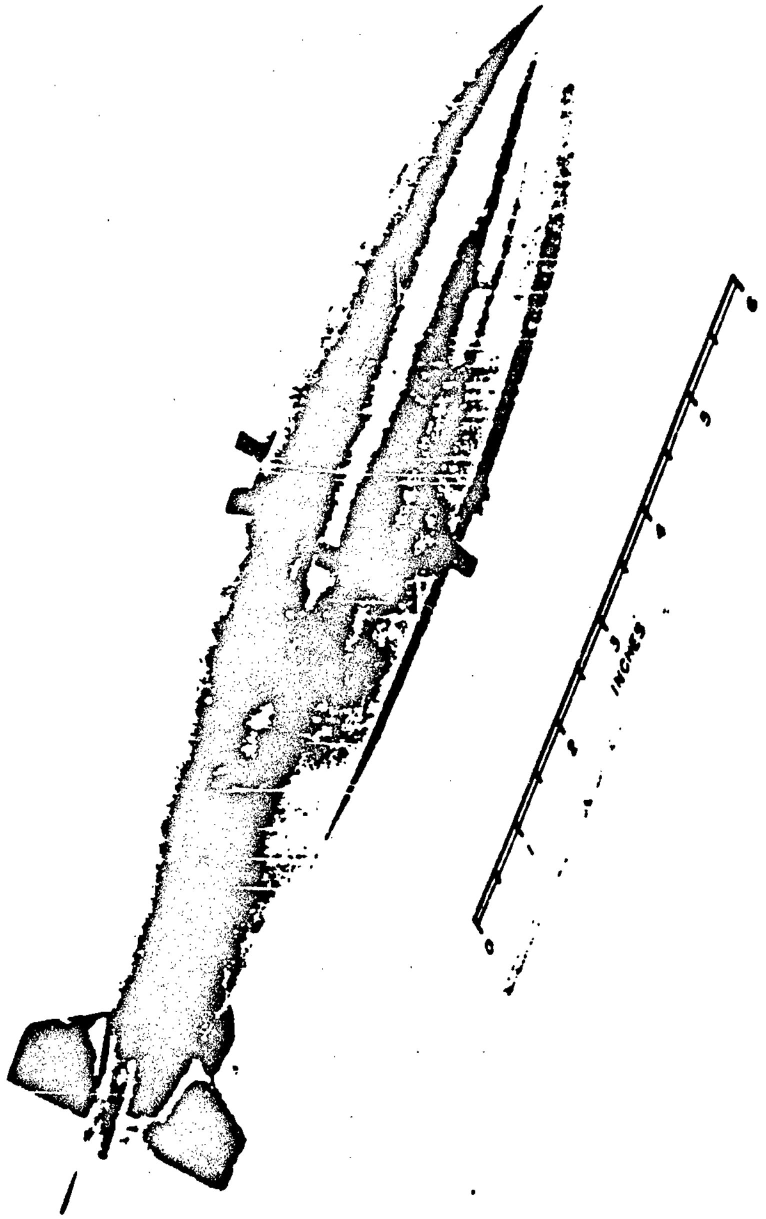


FIG. 8 SMALL NOSE VANES MODEL

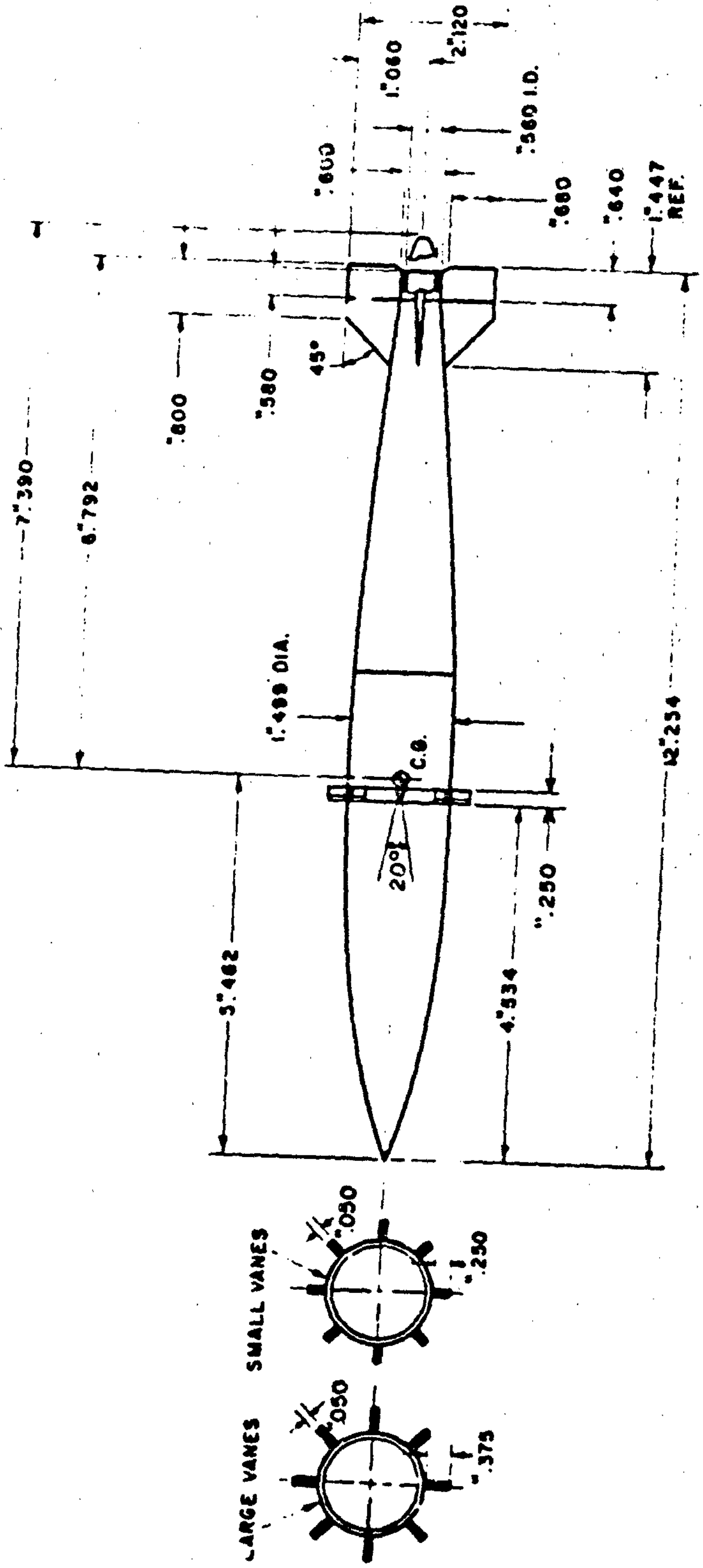


FIG. 9 1000 LB LOW DRAG BOMB
NOSE VANES ATTACHED
(4 FIN-1.40 D SPAN)

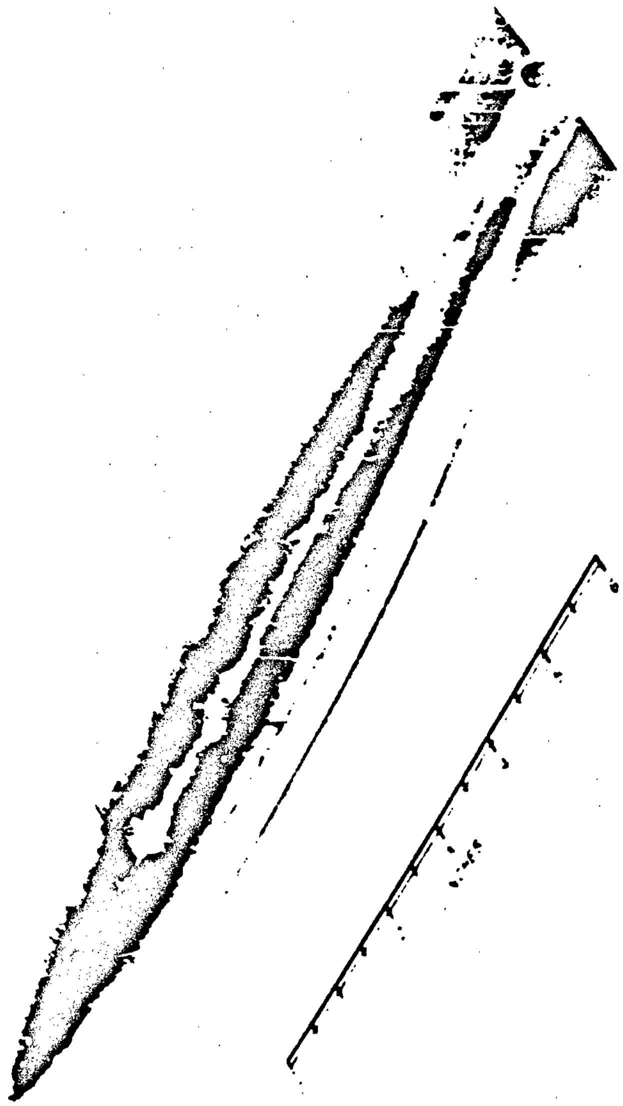


FIG. 10 1.40d FIN SPAN AND CHORD OF 2.05d

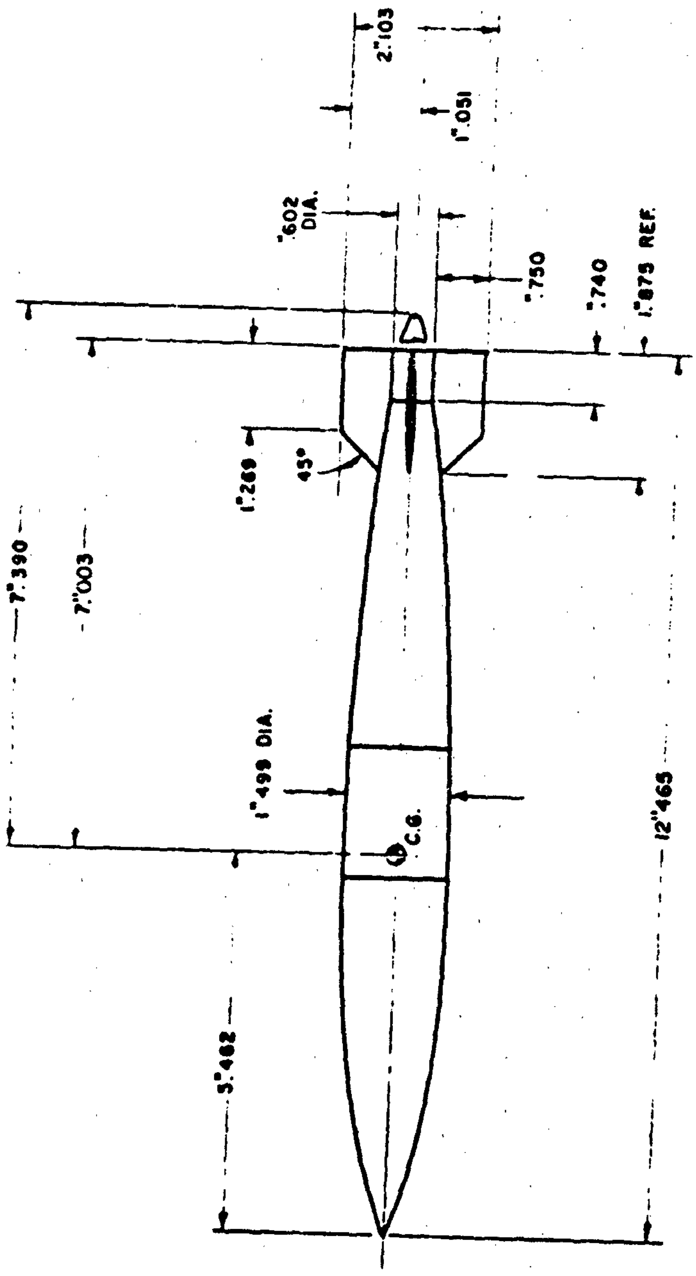


FIG. 11 1000 LB LOW DRAG BOMB
(4 FIN–1.40 D SPAN)

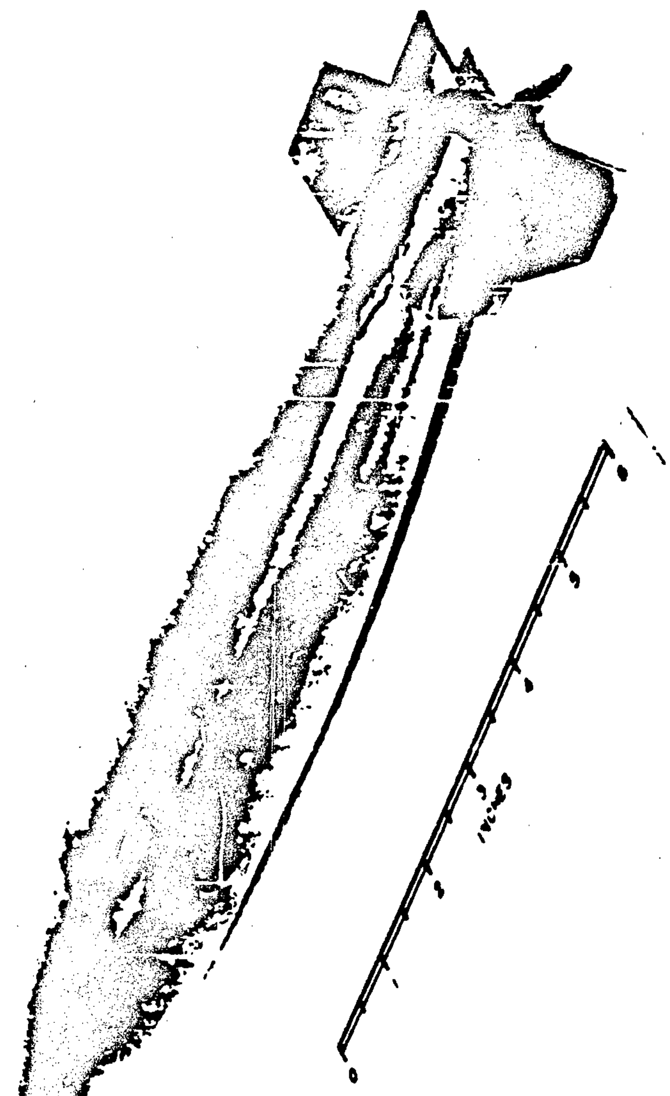


FIG. 12 6-FIN MODEL

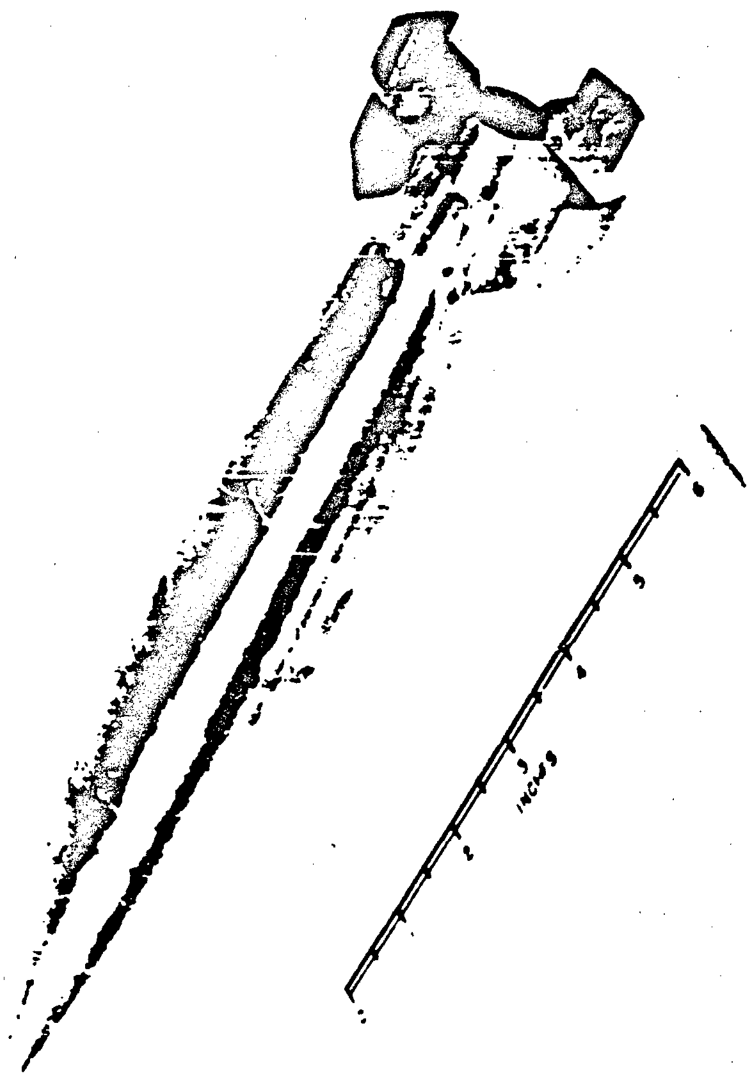


FIG. 13 END PLATE MODEL

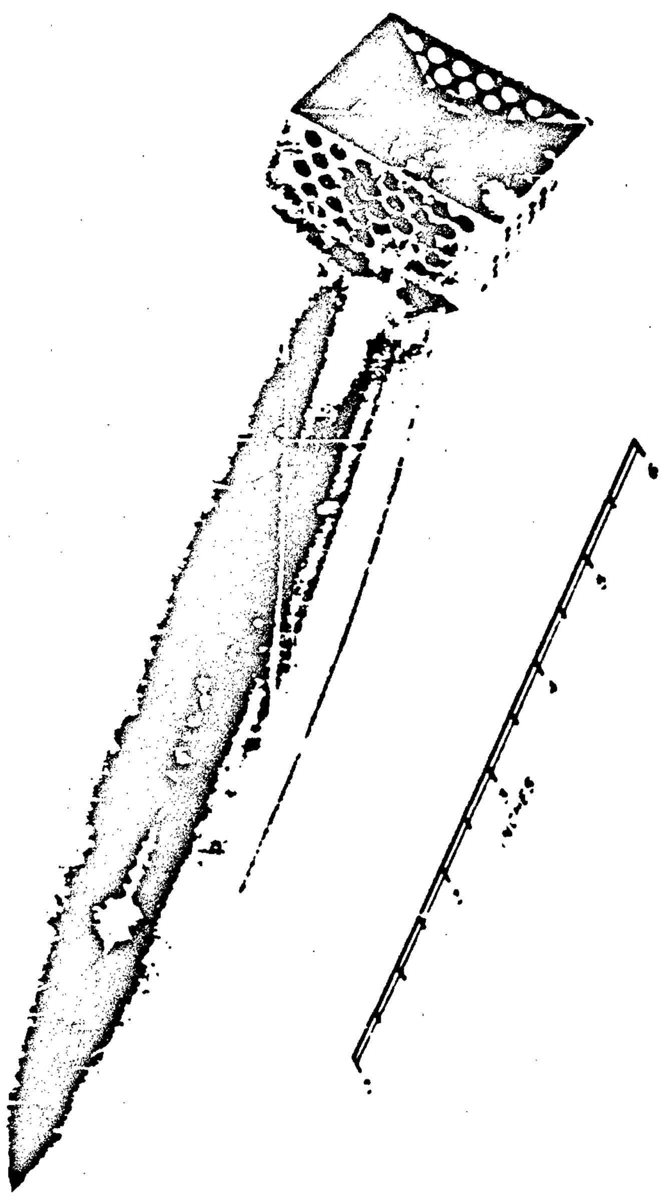


FIG. 14 POROUS BOX MODEL

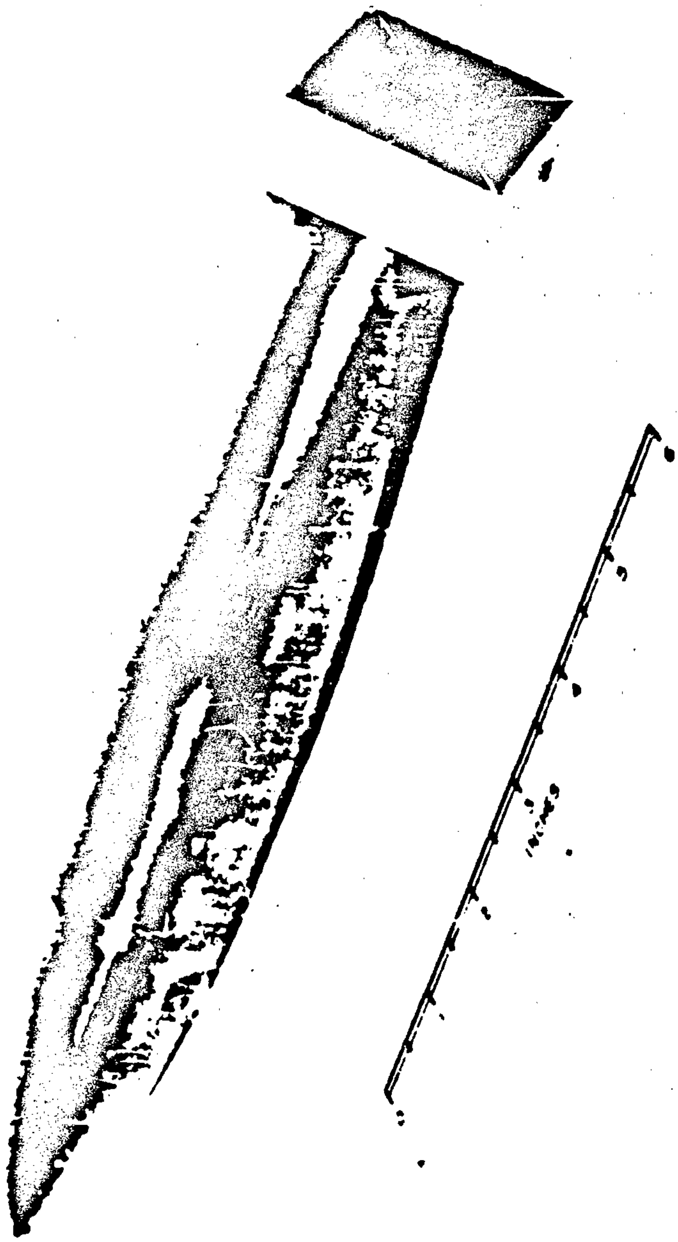


FIG. 15 SOLID BOX MODEL

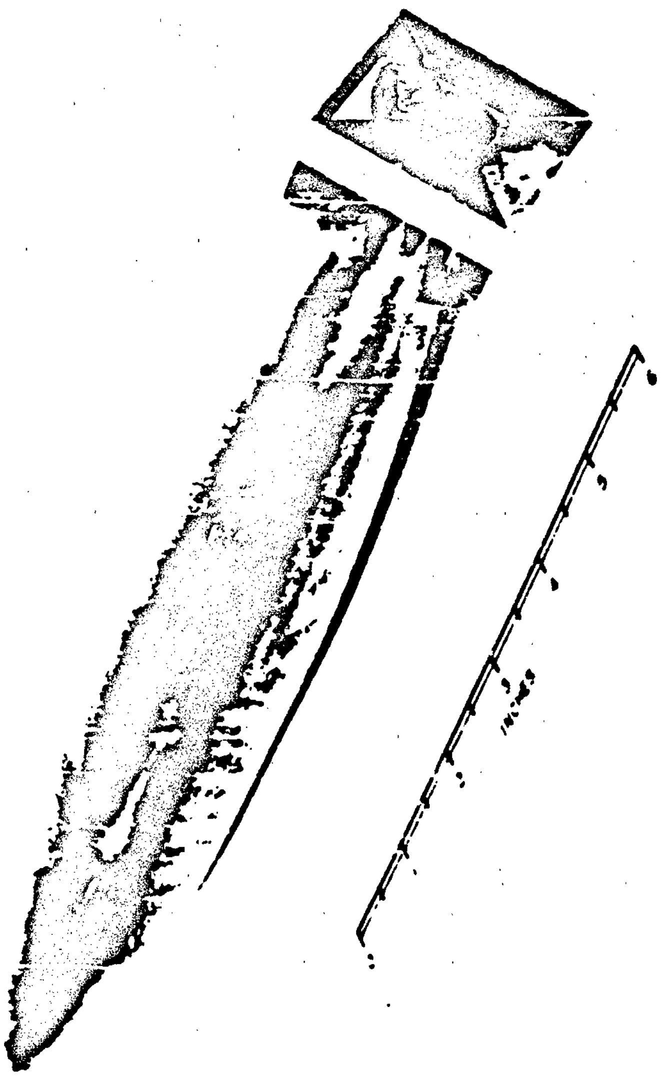


FIG. 16 HALF TIP CHORD SOLID BOX SHROUD MODEL

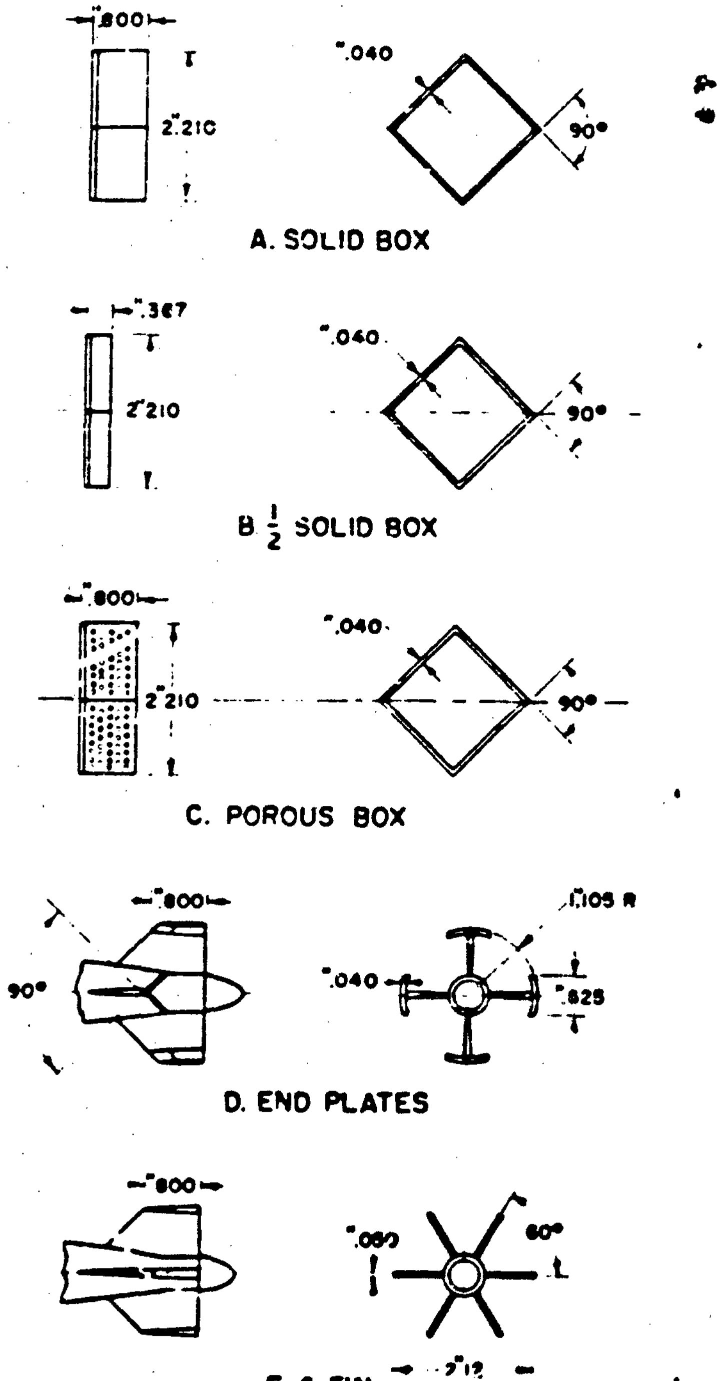


FIG. 17 PARTS TESTED ON LOW DRAG BOMBS

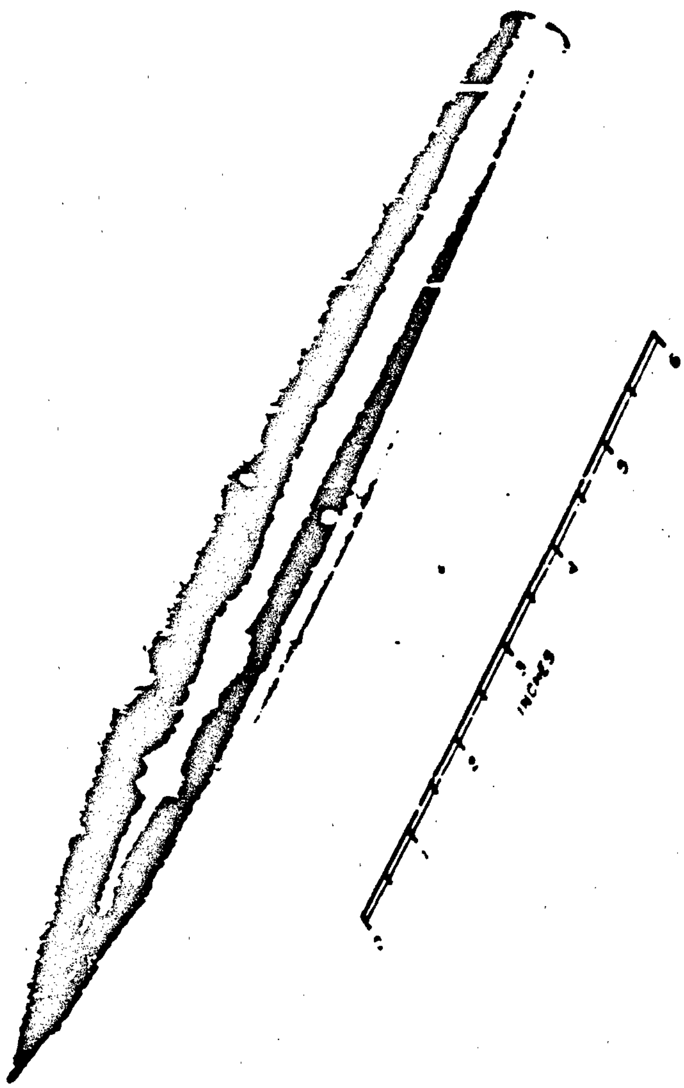


FIG. 18 BODY-ALONE MODEL

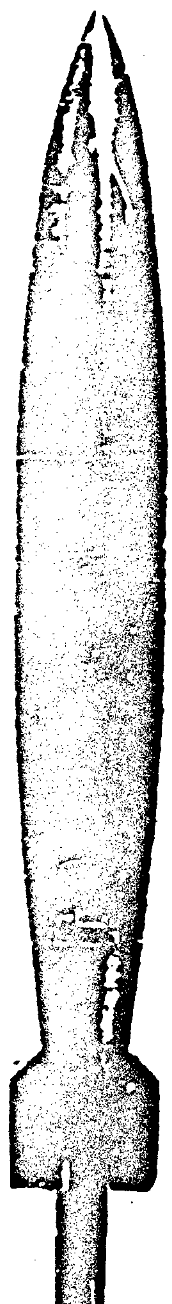


FIG. 19 8-FIN MODEL

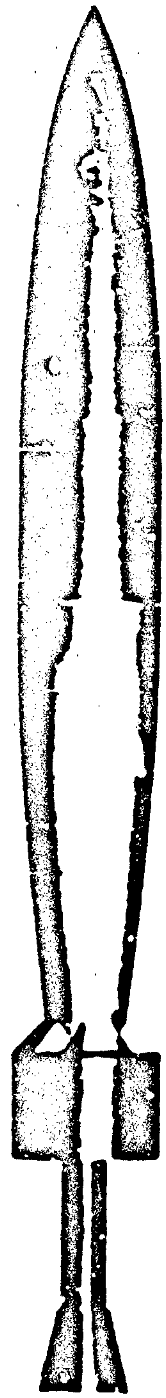


FIG. 20 8-FIN MODEL (FULL CIRCULAR SHROUD)

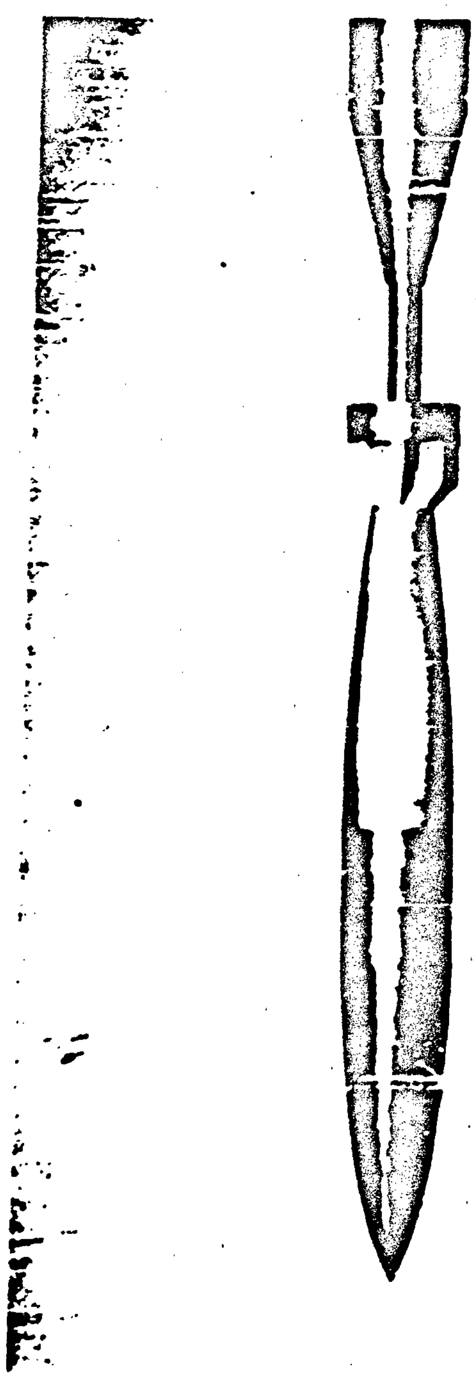


FIG. 21 8-FIN MODEL (HALF CIRCULAR SHROUD)

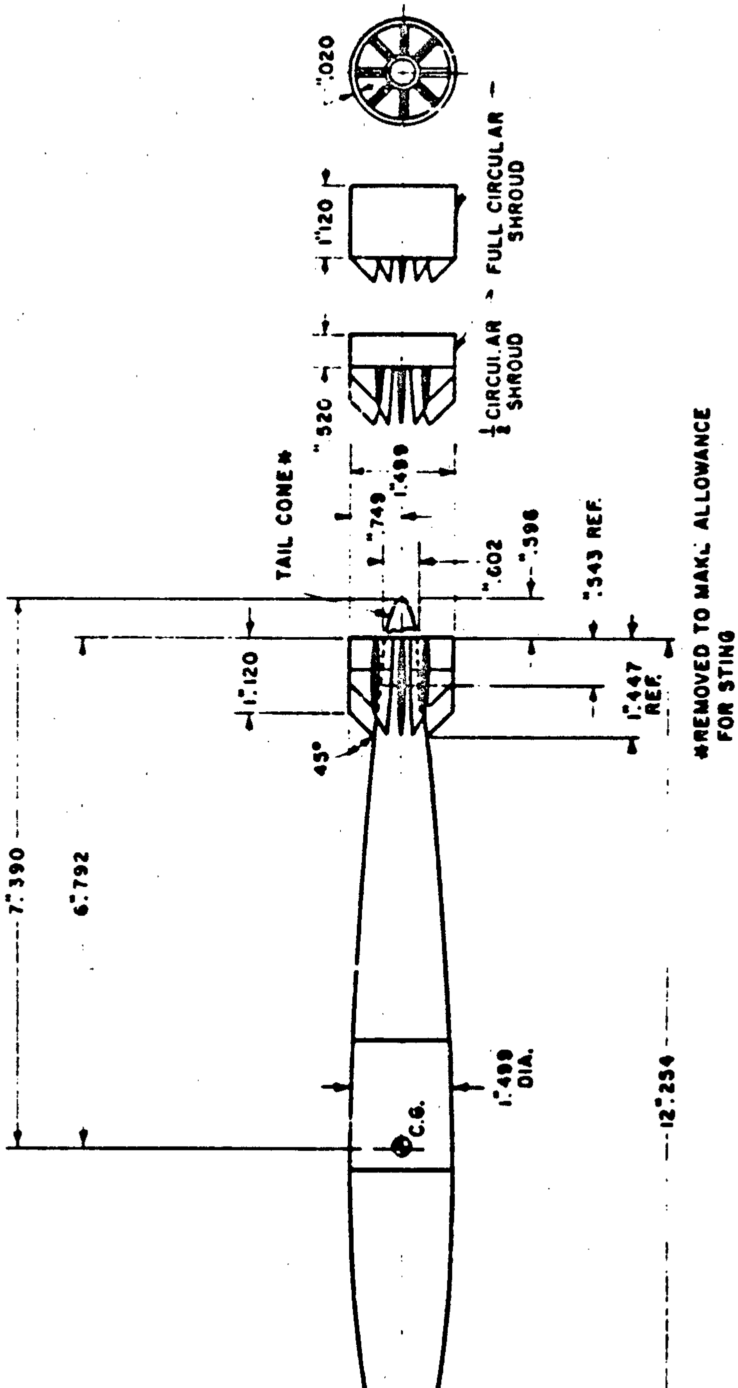


FIG. 22 1000 LB LOW DRAG BOMB
(8 FIN—1.00 D SPAN)

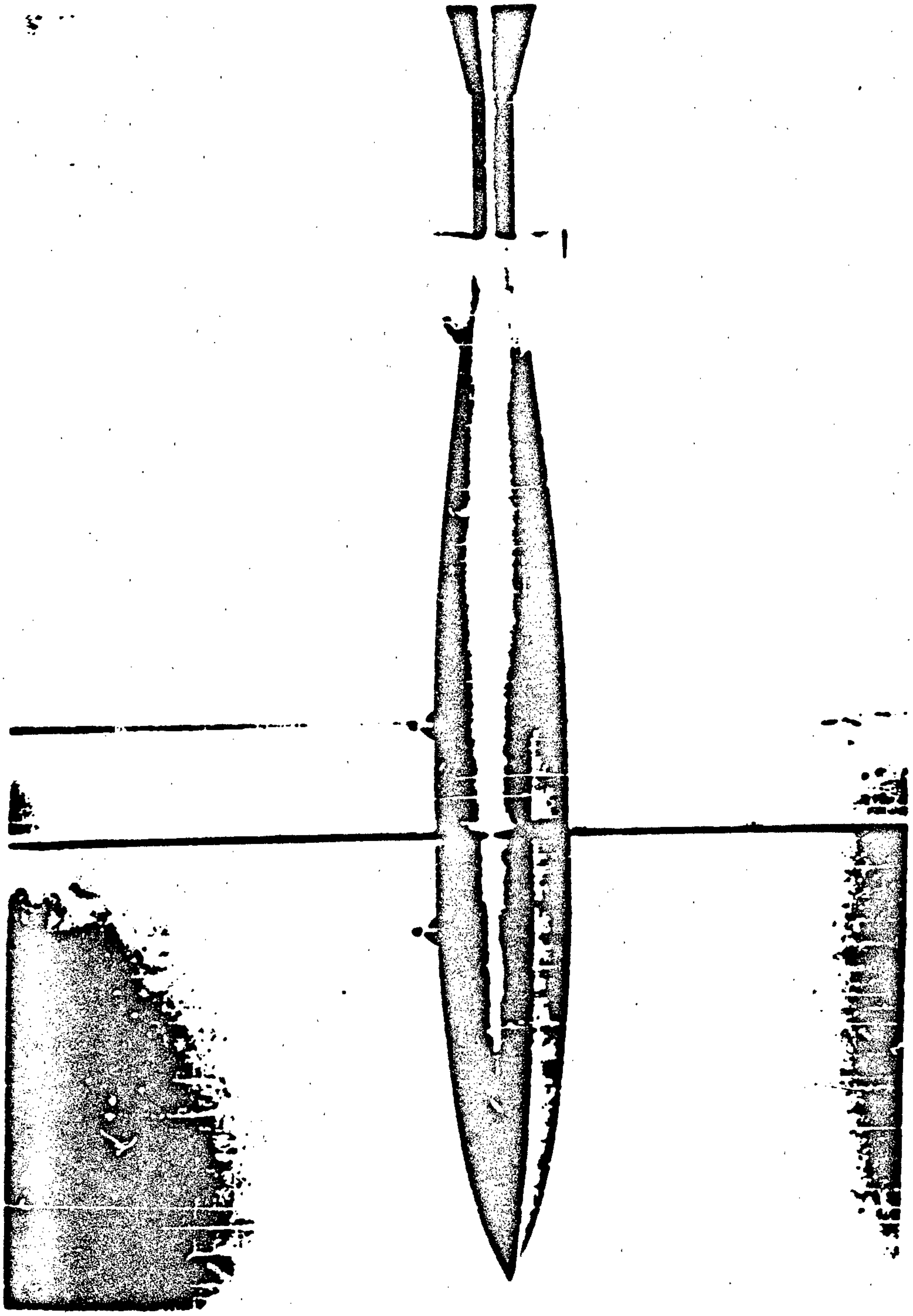


FIG. 23 250-POUND LOW-DRAG BOMB MODEL WITH LUGS

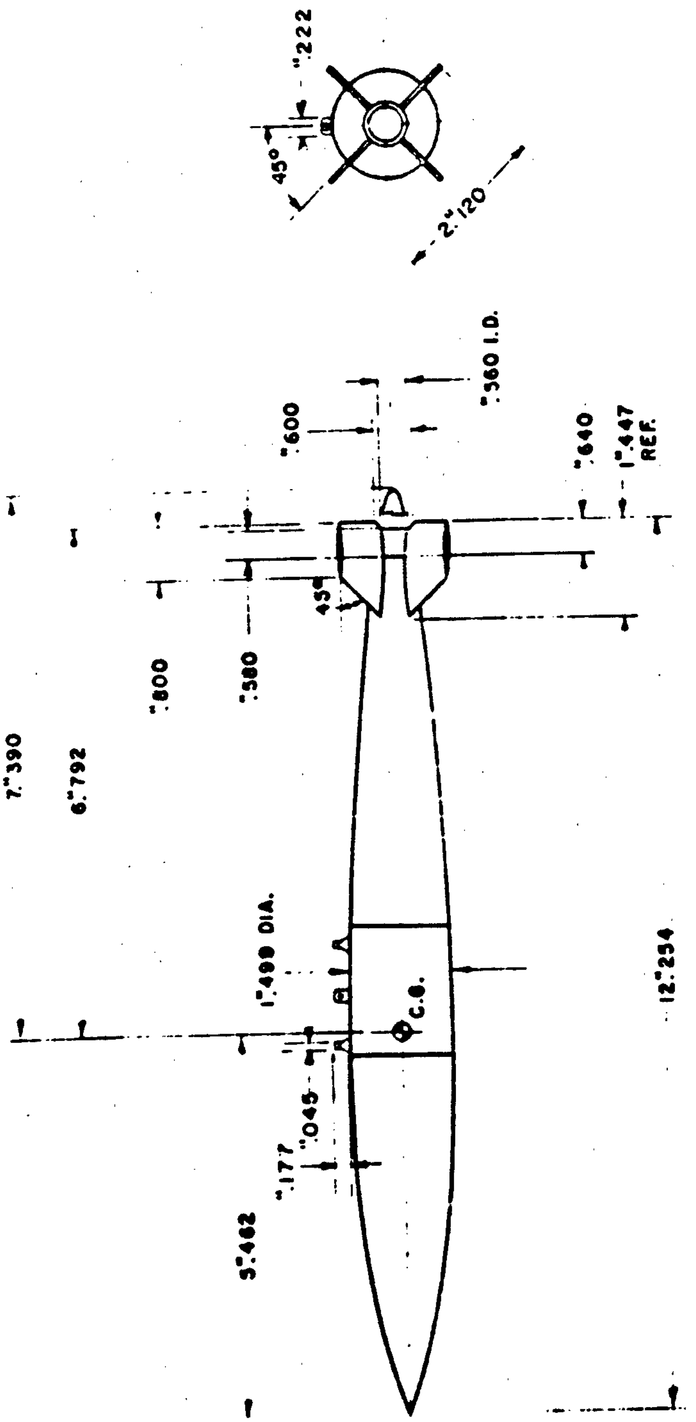


FIG. 24 250 LB LOW DRAG BOMB,
1000 LB BOMB LUGS ATTACHED
(4 FIN – 1.40 D SPAN)

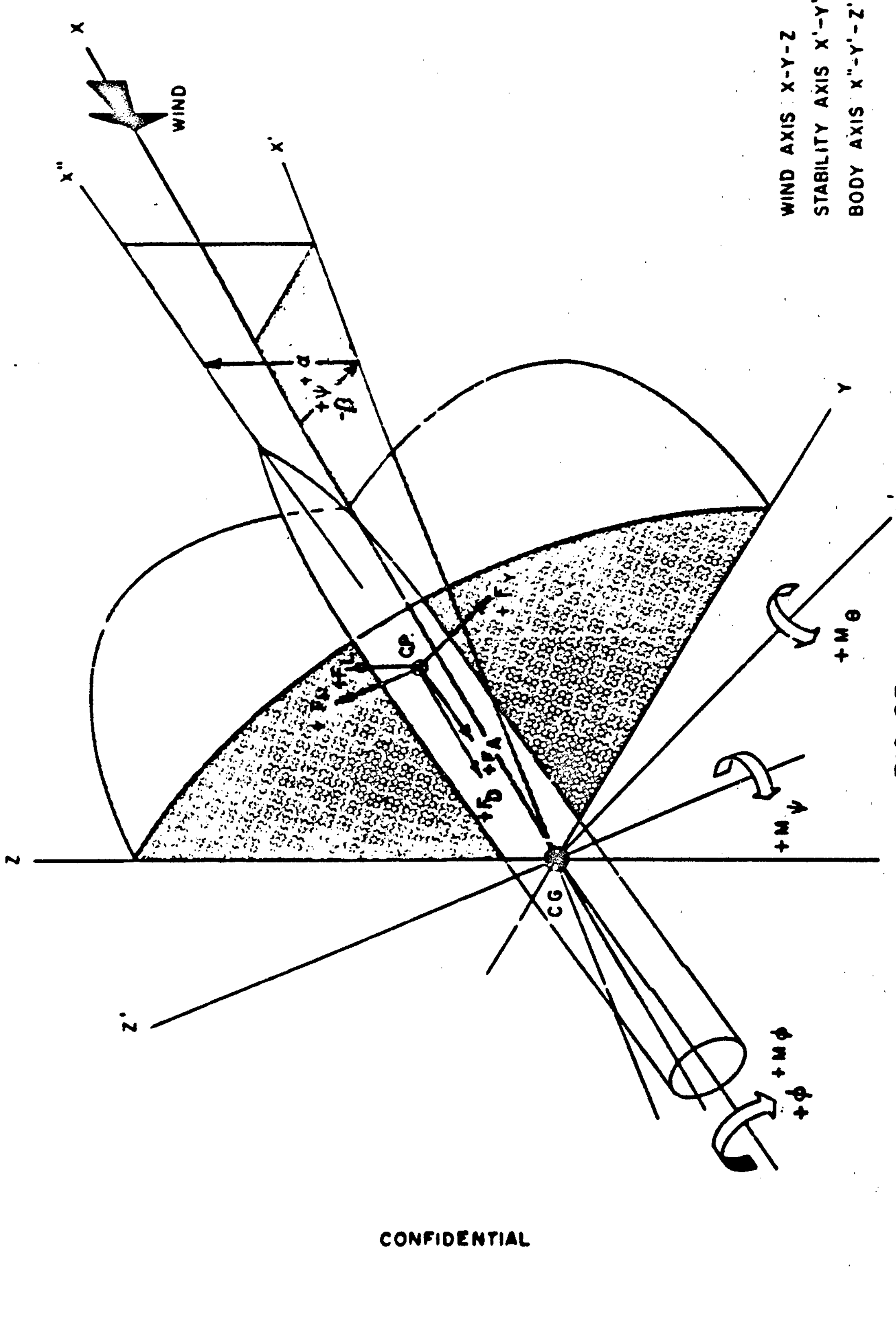

WIND AXIS X-Y-Z
STABILITY AXIS X'-Y'-Z'
BODY AXIS X"-Y'-Z'
WIND
X
X'
X"
Y
Y'
Z
Z'
CG
CP
+α
+ψ
-β
+D
+A
+Mθ
+Mψ
+Mφ
+φ

FIG. 25

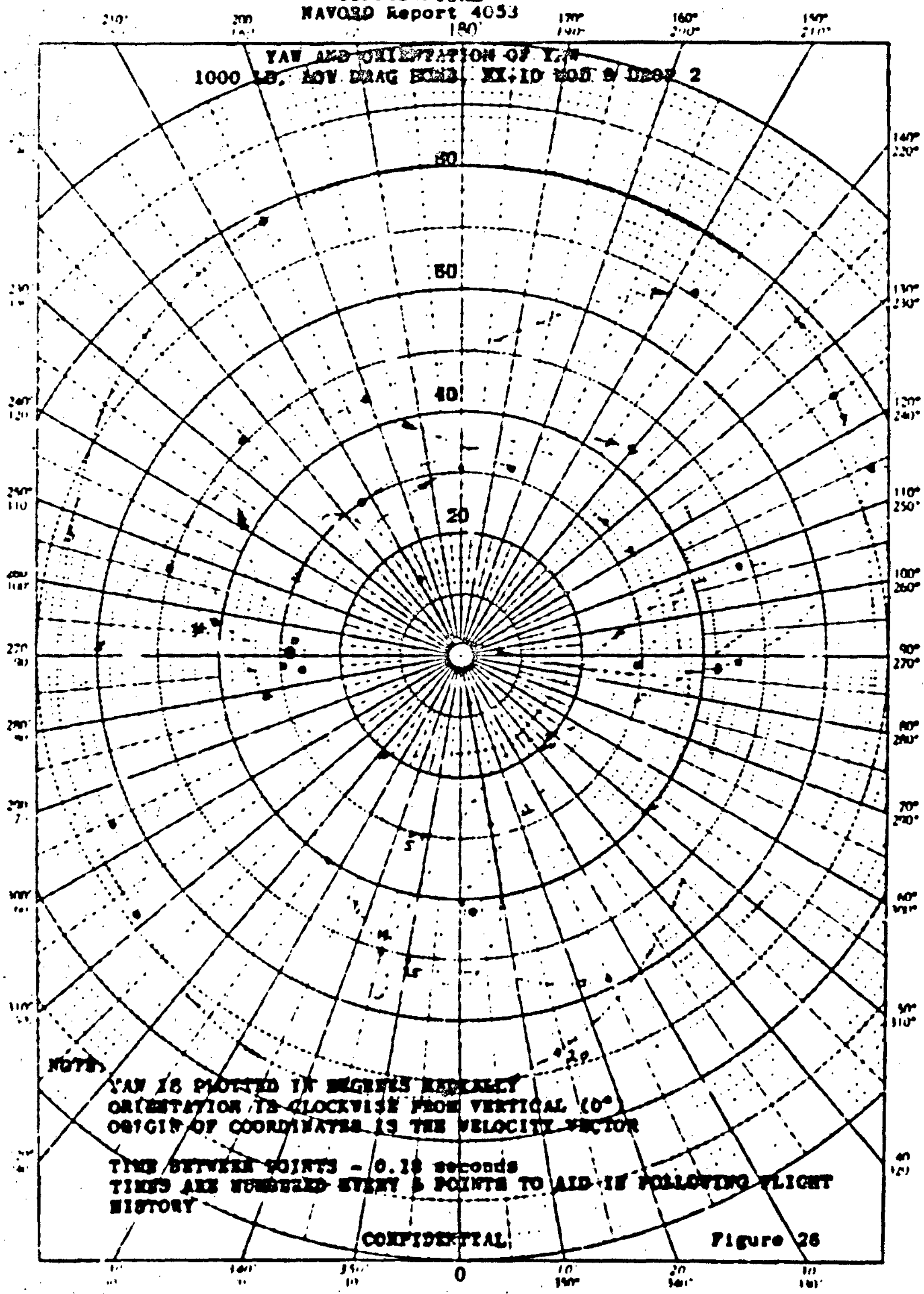

YAW AND ORIENTATION OF YAW
1000 LB. LOW DRAG BOMB, MK 10 MOD 8 DROP 2
NOTE:
YAW IS PLOTTED IN DEGREES RADIALLY
ORIENTATION IS CLOCKWISE FROM VERTICAL (0°)
ORIGIN OF COORDINATES IS THE VELOCITY VECTOR
TIME BETWEEN POINTS - 0.18 seconds
TIMES ARE NUMBERED EVERY 5 POINTS TO AID IN FOLLOWING FLIGHT HISTORY

Figure 26

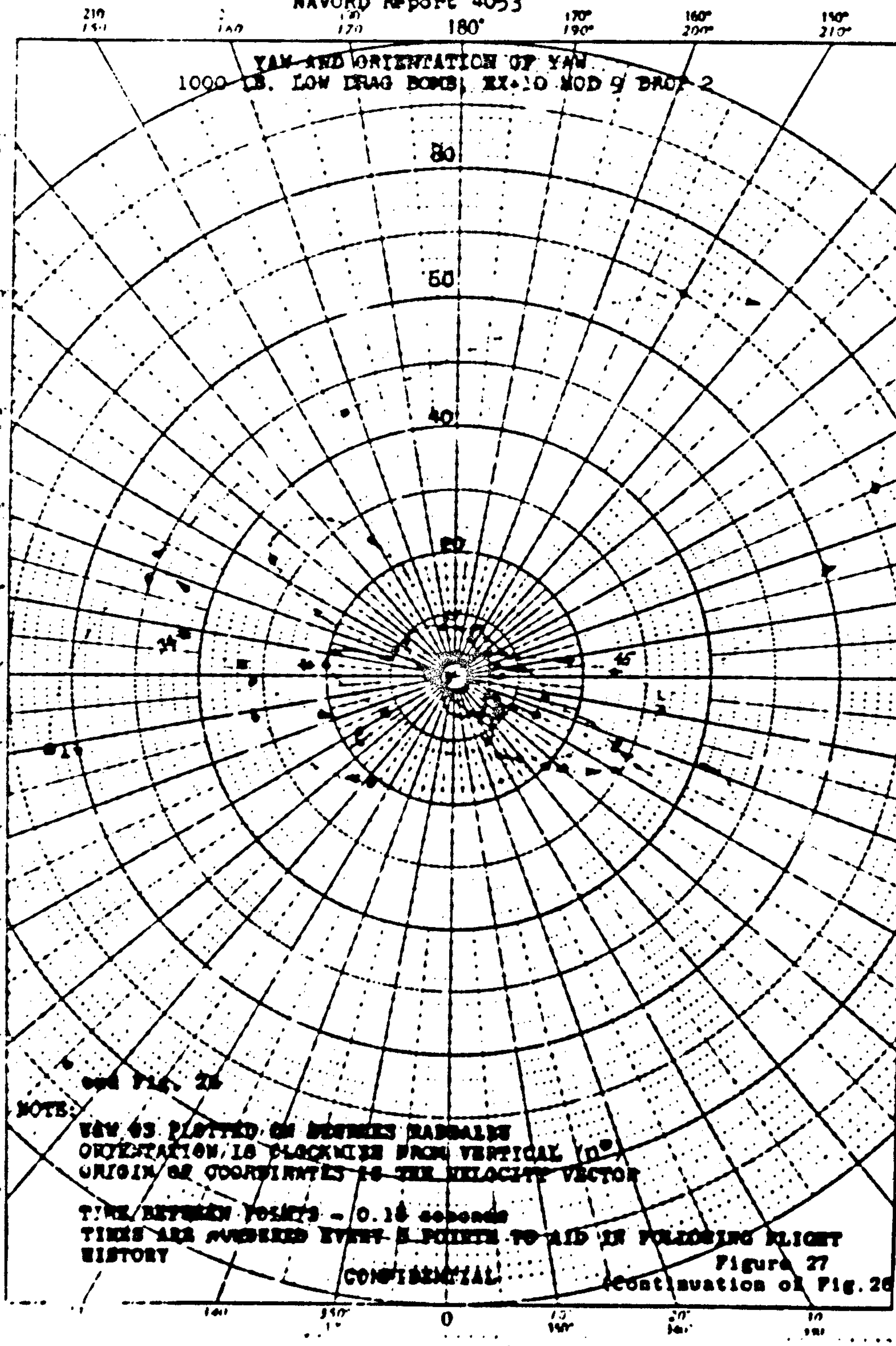
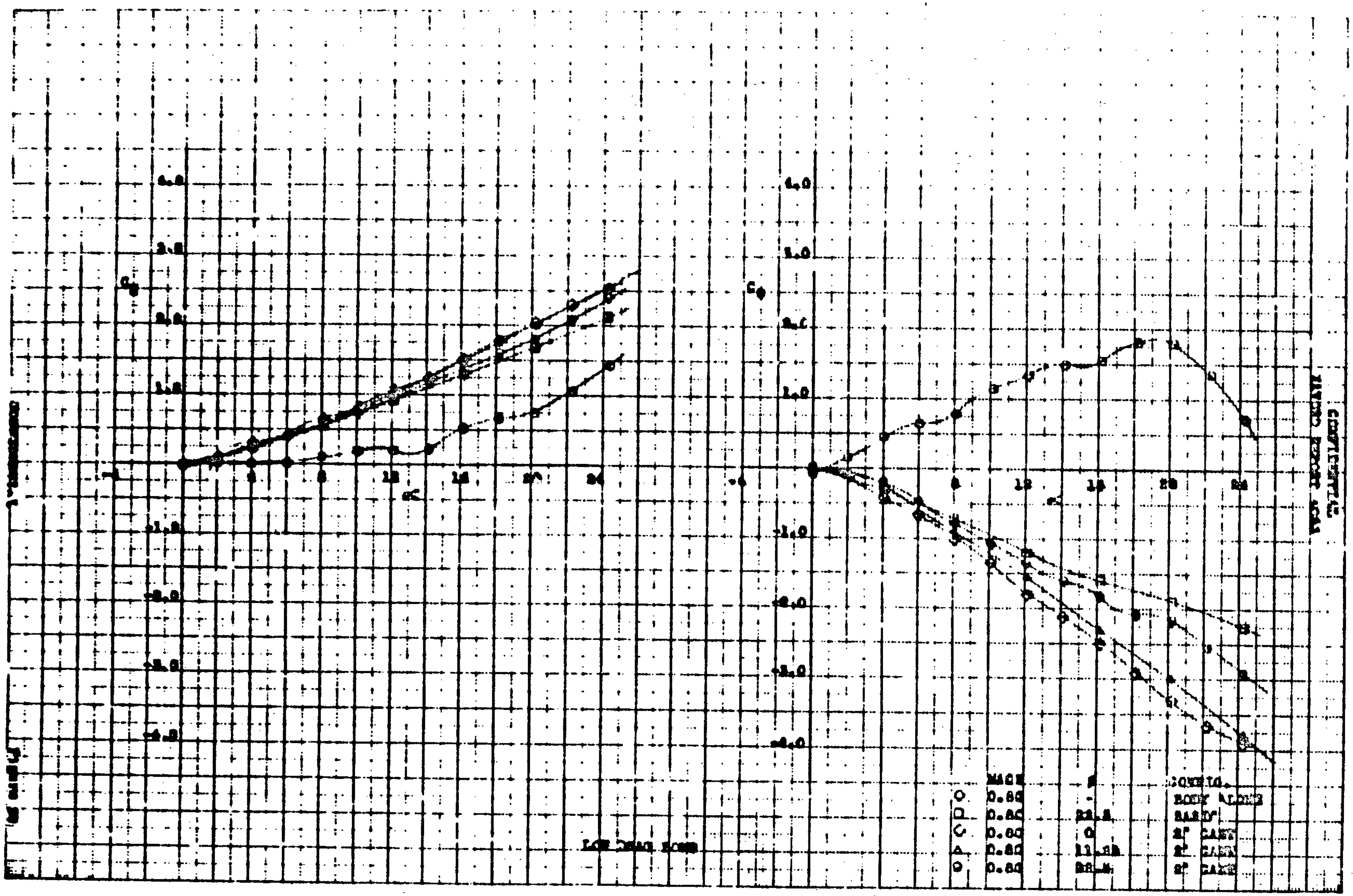
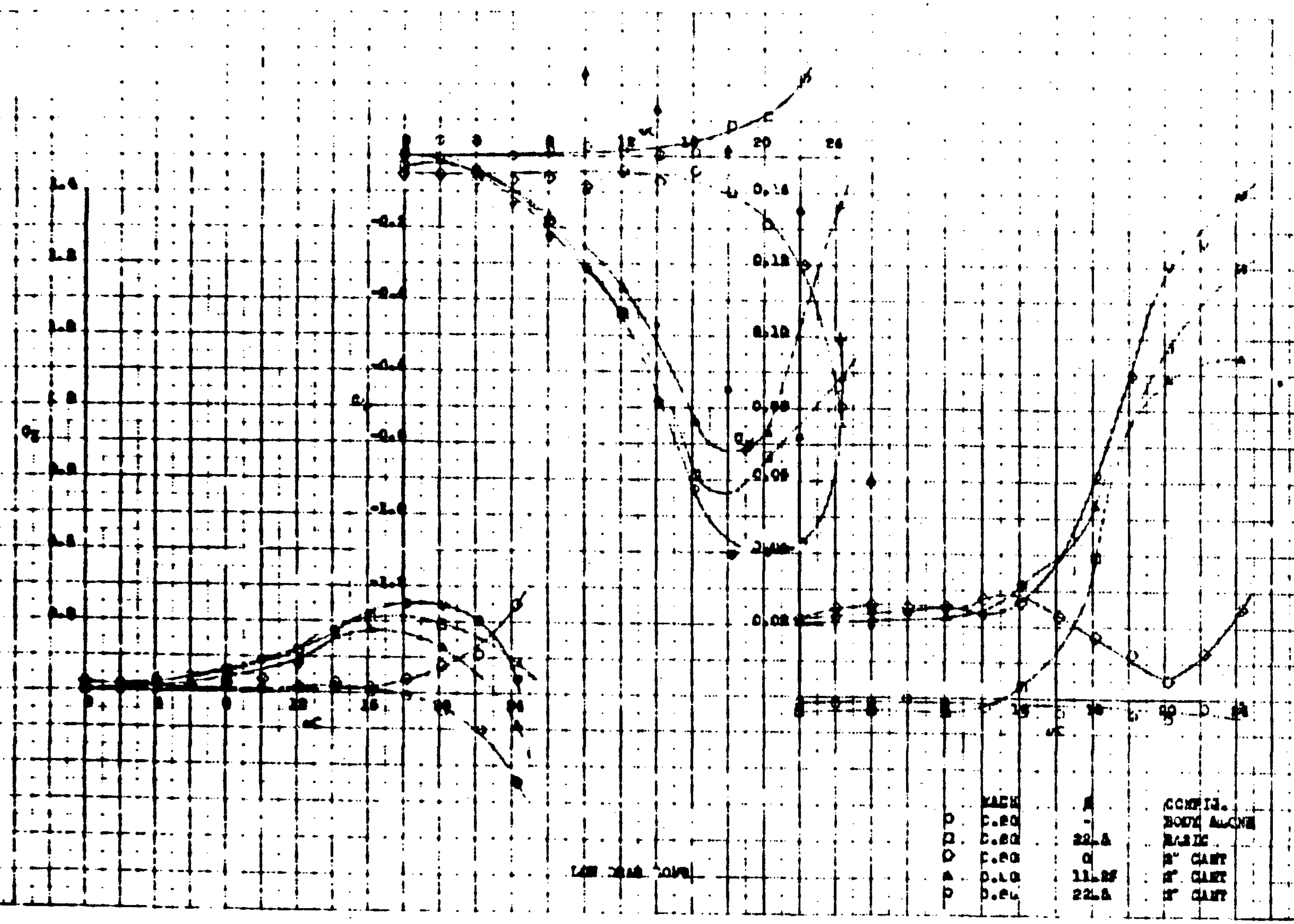
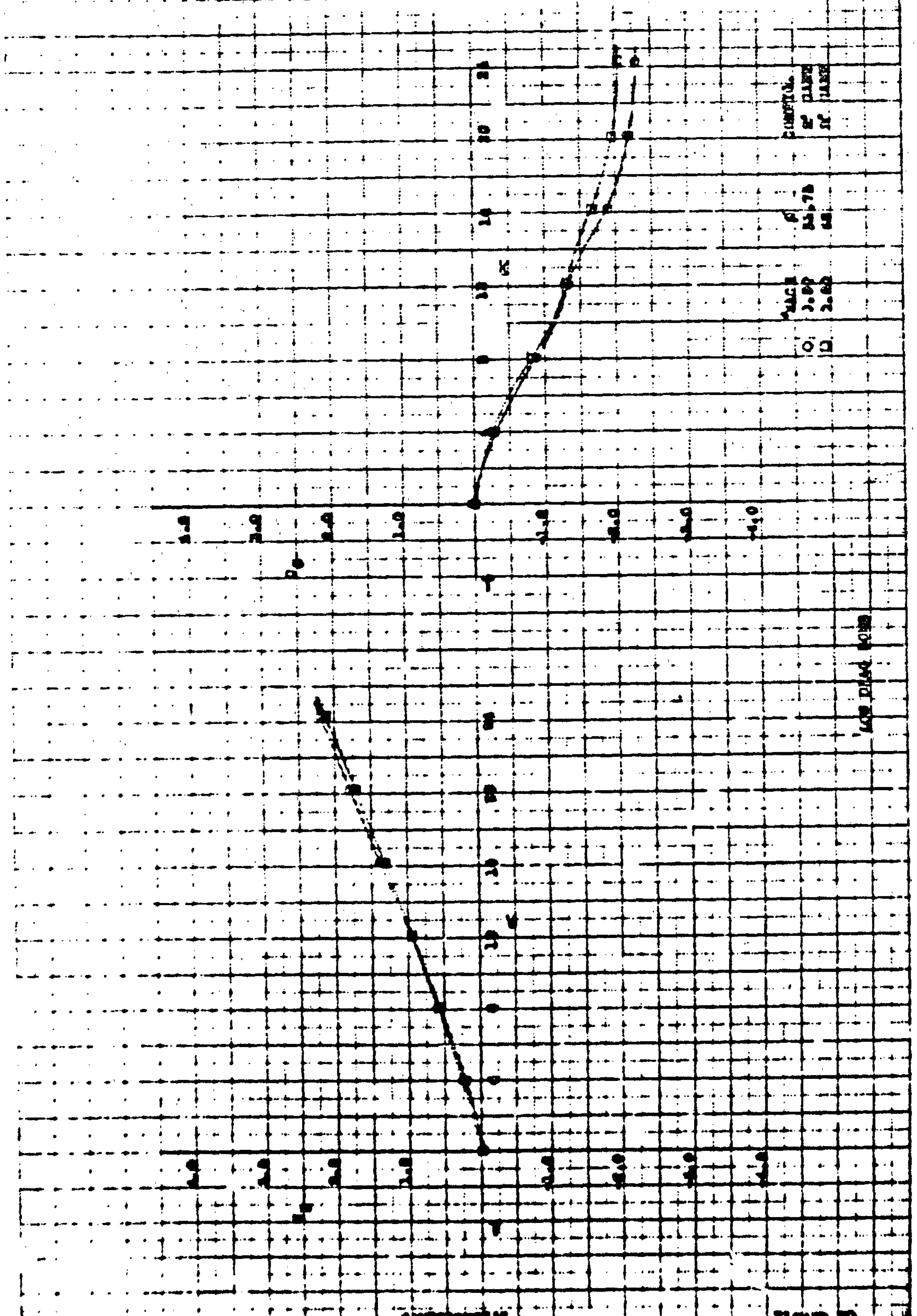


Figure 27
(Continuation of Fig. 26)


LOW DRAG BOMB
MACH
CONFIG.
BODY ALONE
0.80


LOW DRAG CONE
MACH β CONFIG.
BODY ALONE
22.5 BASIC
0 8" CANT
11.25 8" CANT
22.5 8" CANT
C_N
C_m
C_D
α



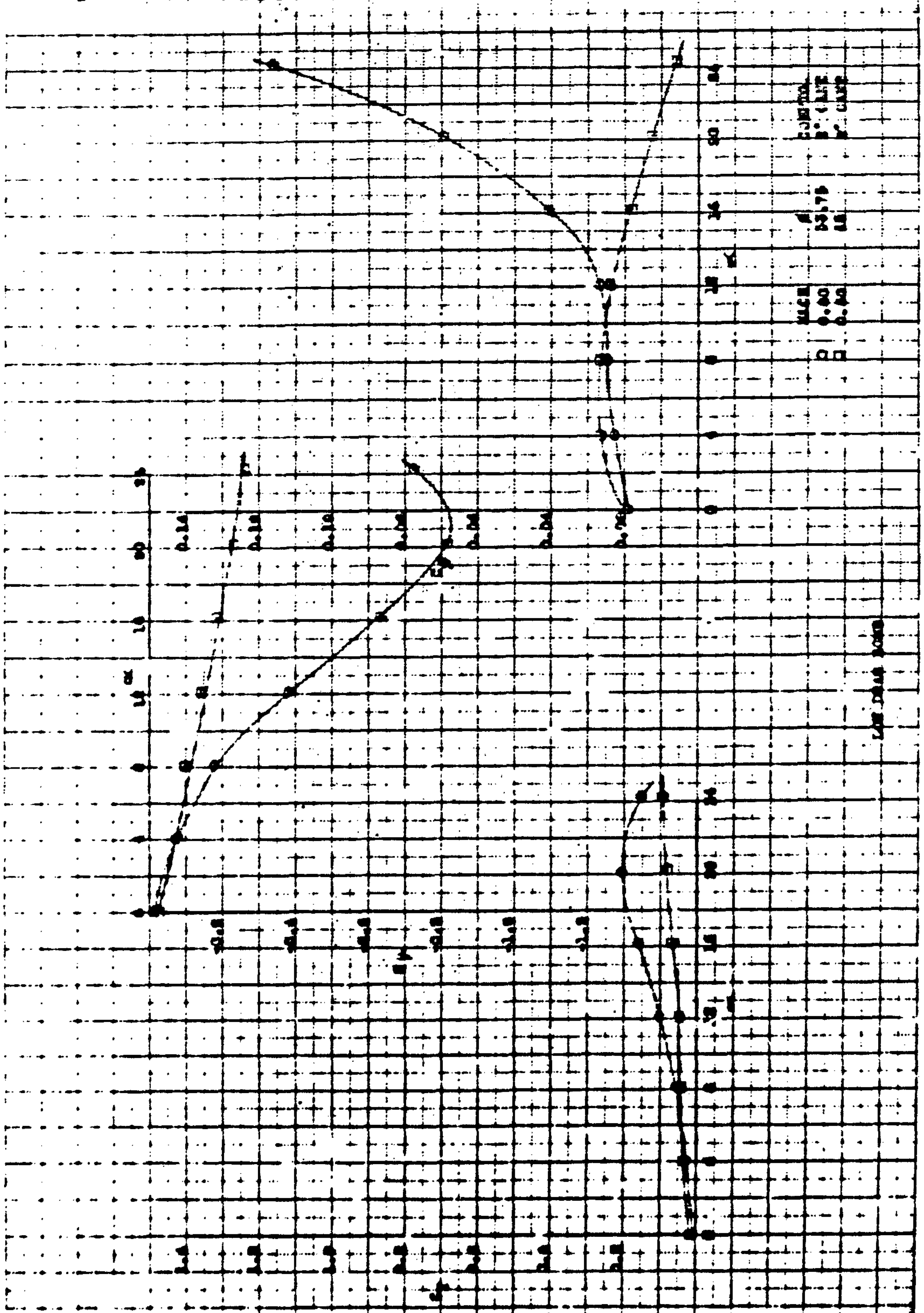
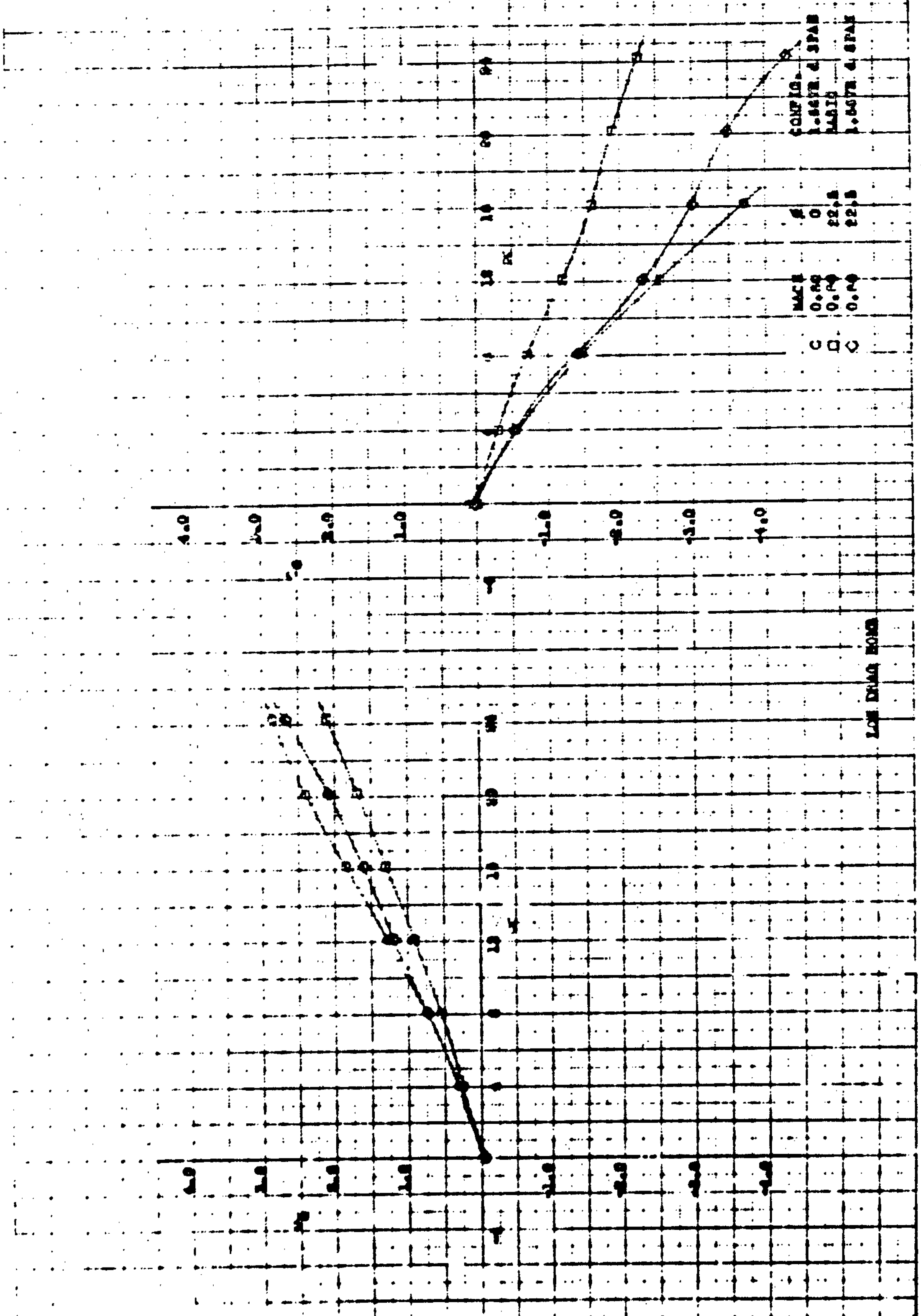
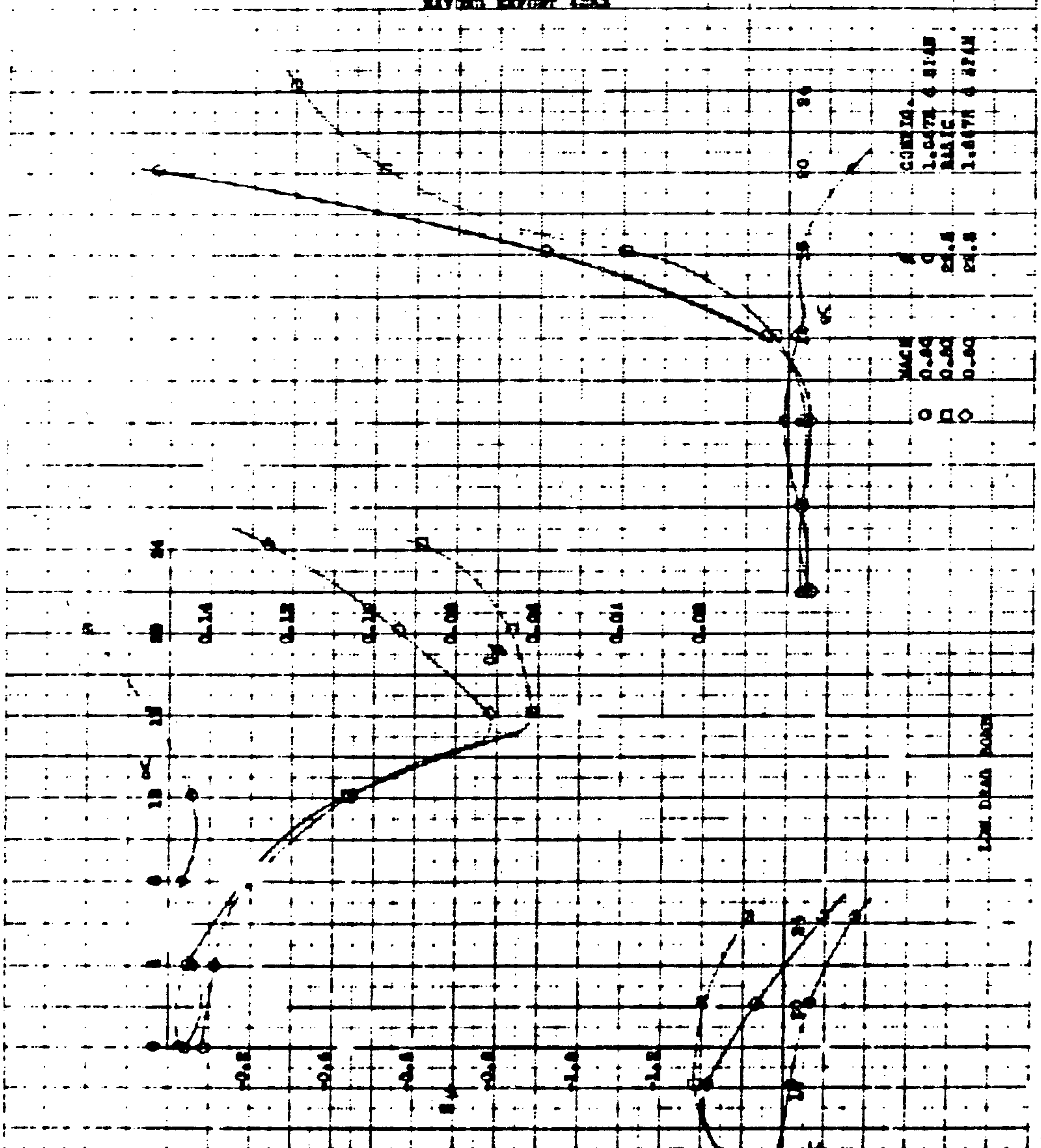
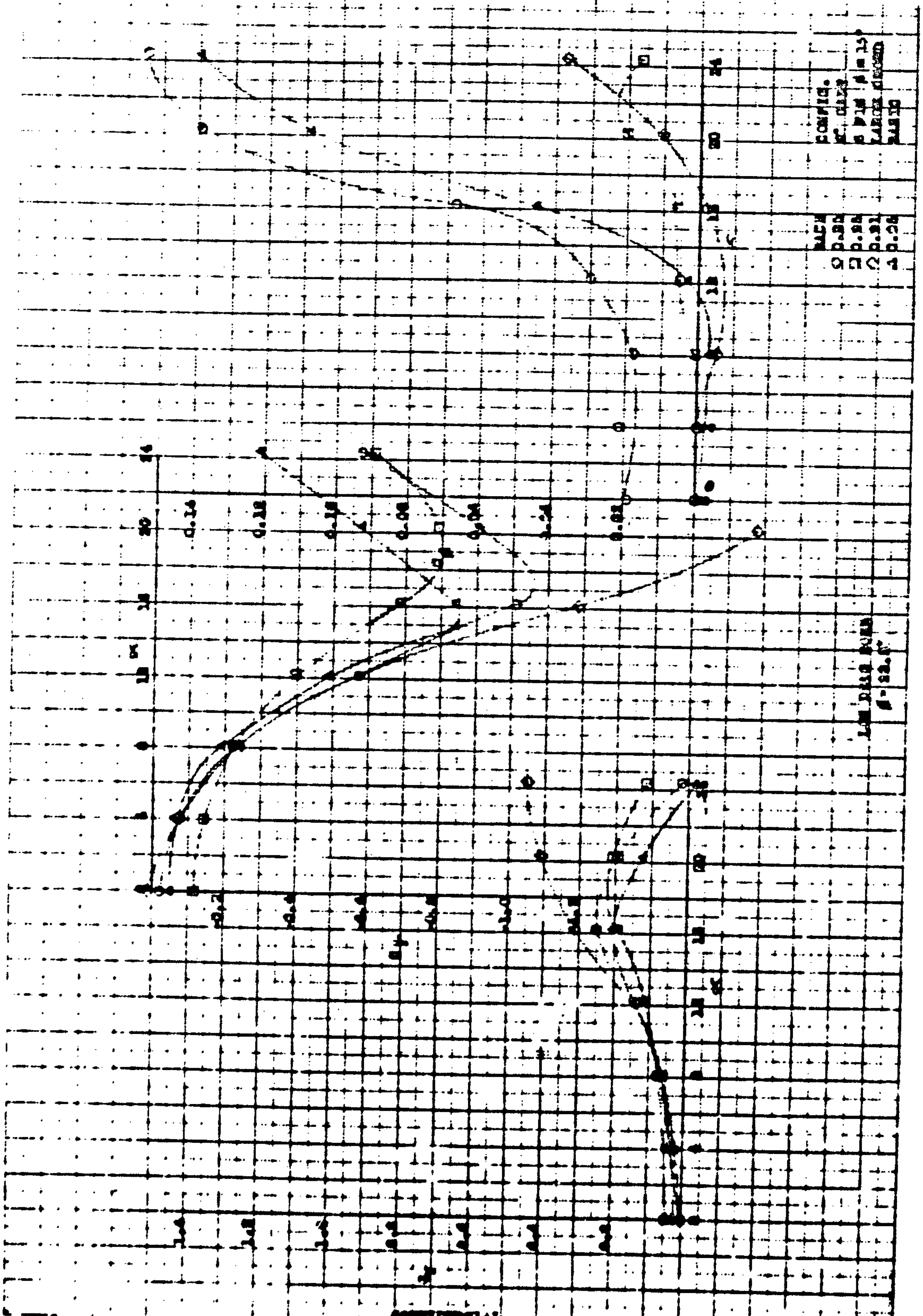
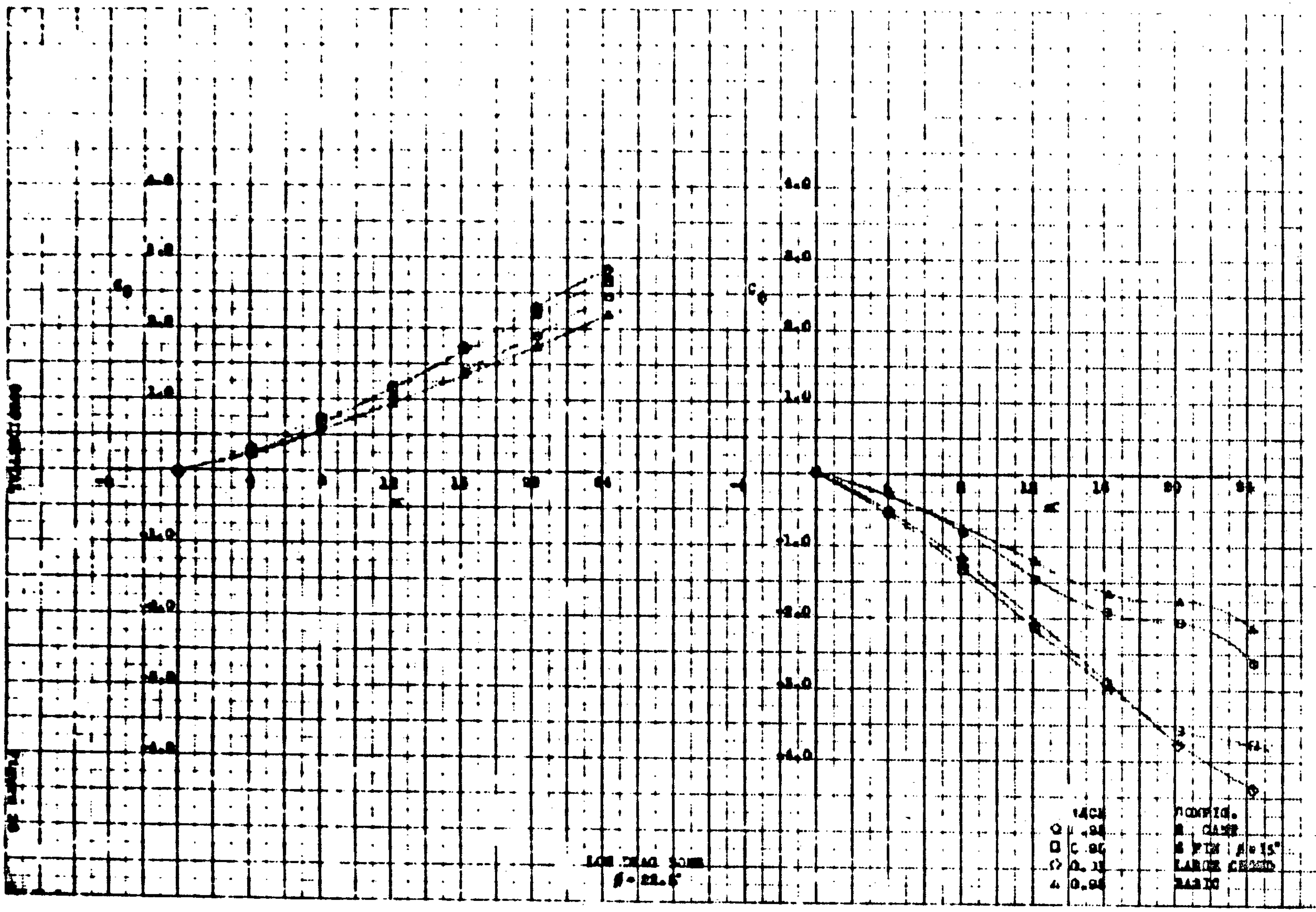


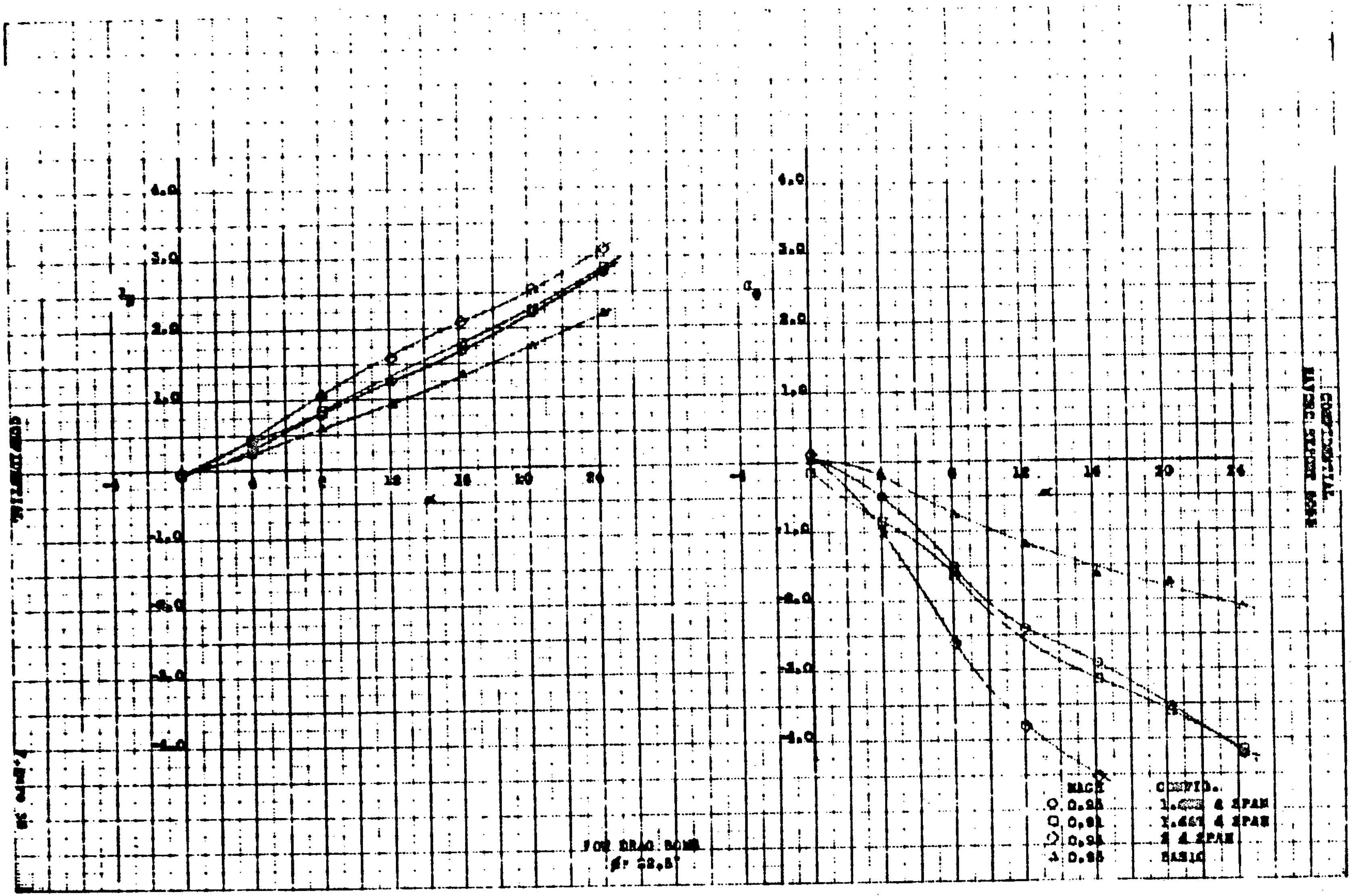
Figure 11

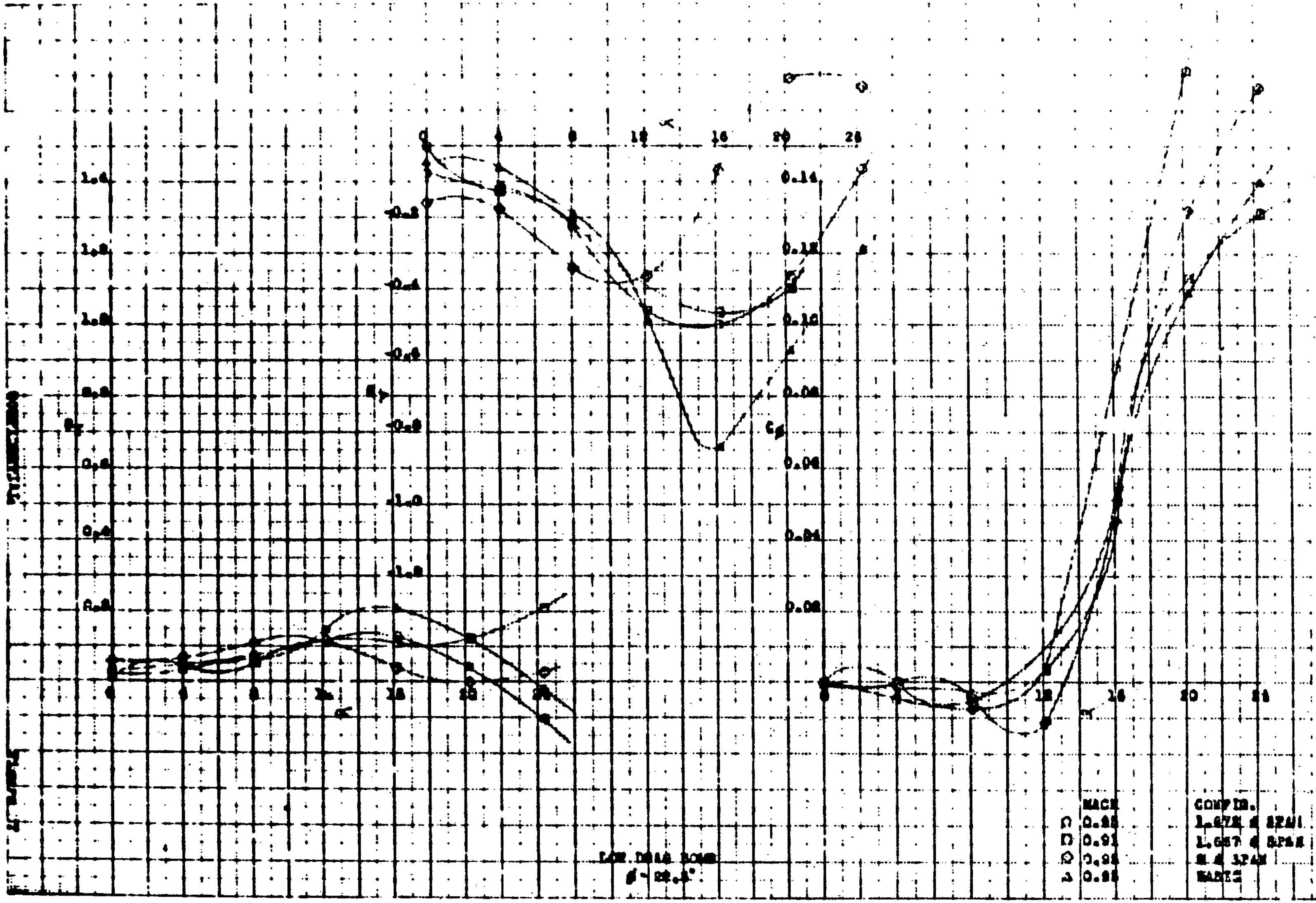

LOW DRAG BOMB
MACH
CONFIG.
BASIC

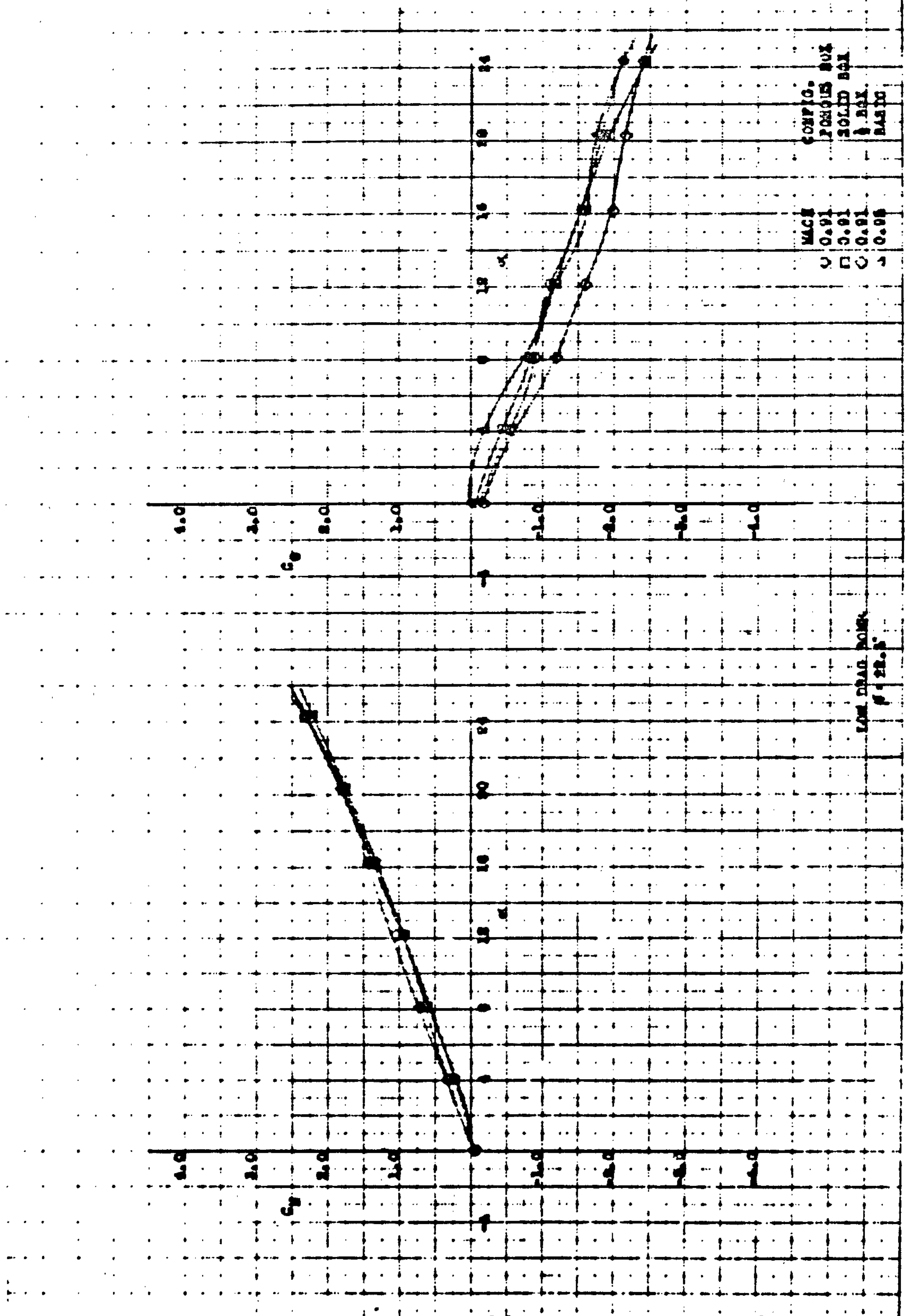

MACH
δ
CONFIG.
0.80
0
1.667R ∆ SPAN
0.80
22.5
BASIC
0.80
22.5
1.667R ∆ SPAN
LOW DRAG BOOM

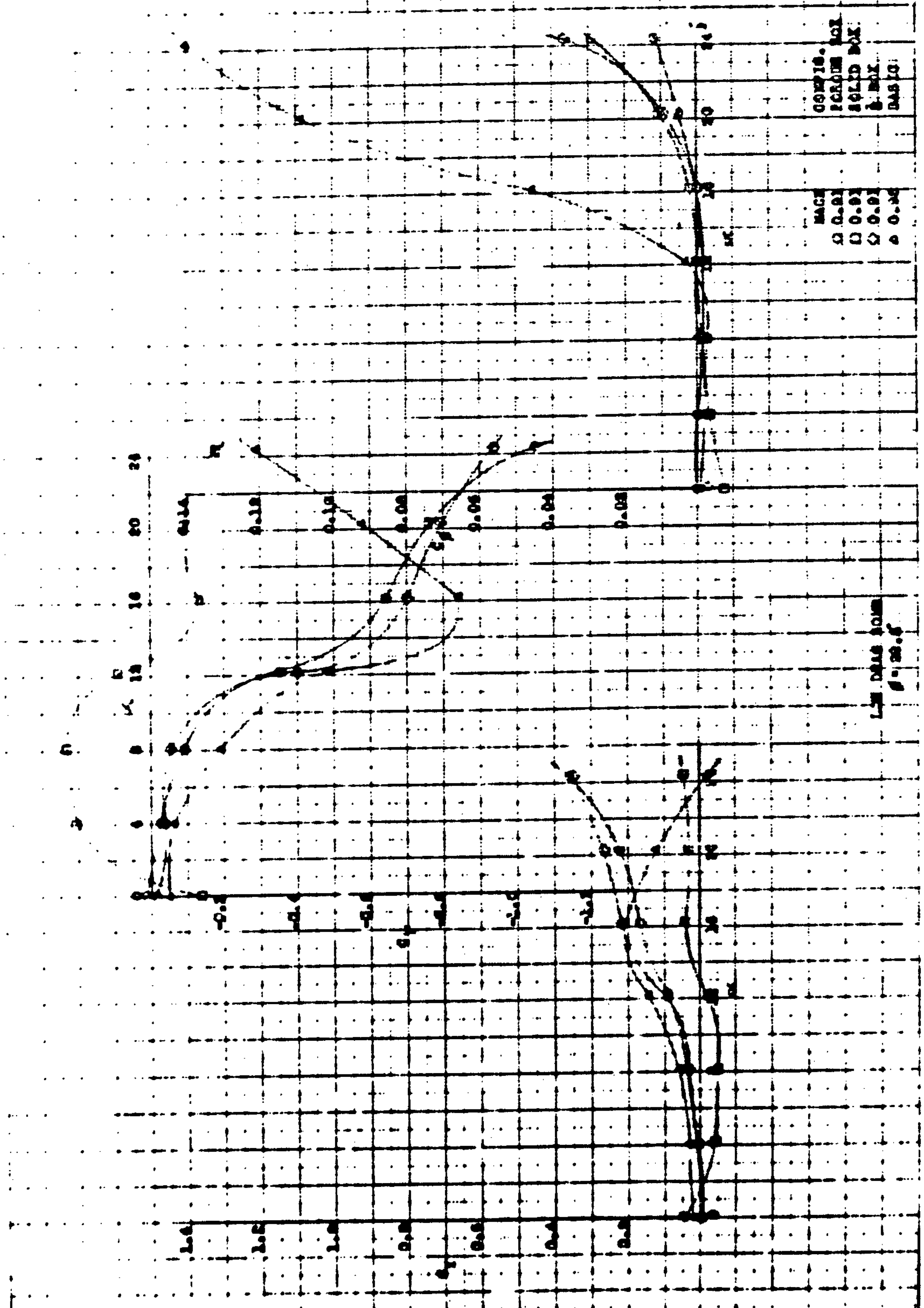


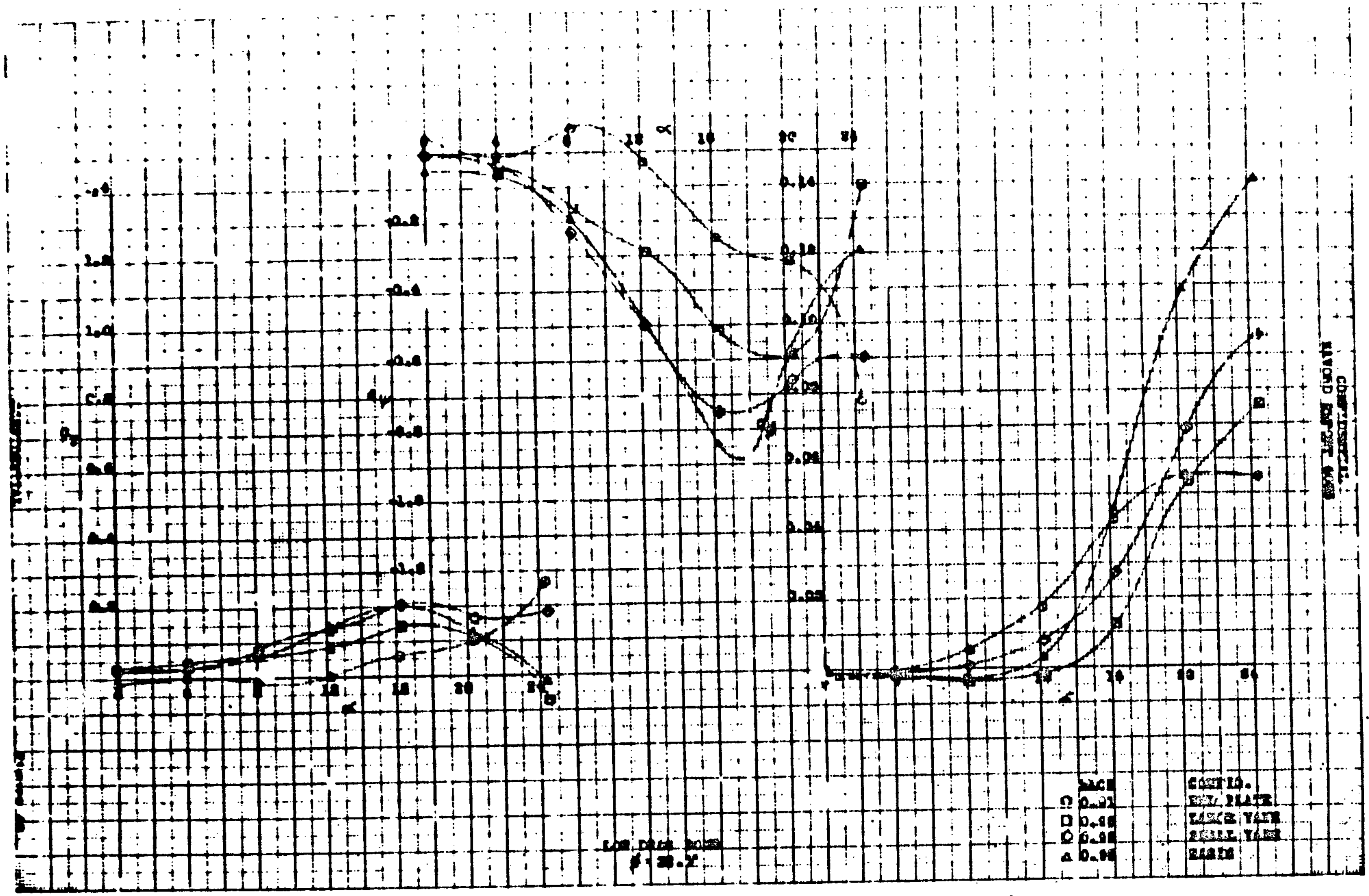

C_ϕ
α
LOW DRAG ZONE
β = 22.5°
MACH
CONFIG.
LARGE CHORD


MACH
CONFIG.
BASIC
FOR DRAG BOMB


LOW DRAG BOMB
MACH
0.85
0.91
0.95
0.98
CONFIG.


MACH
0.91
0.91
0.91
0.98
CONFIG.
POROUS BOX
SOLID BOX
½ BOX
BASIC
LOW DRAG BOMB




LOW DRAG BOMB
β = 28.7°
MACH
0.91
0.95
0.98
0.98
CONFIG.
HOR. PLATE
LARGE VANE
SMALL VANE
BASIC
α
C_y
C_N
C_m

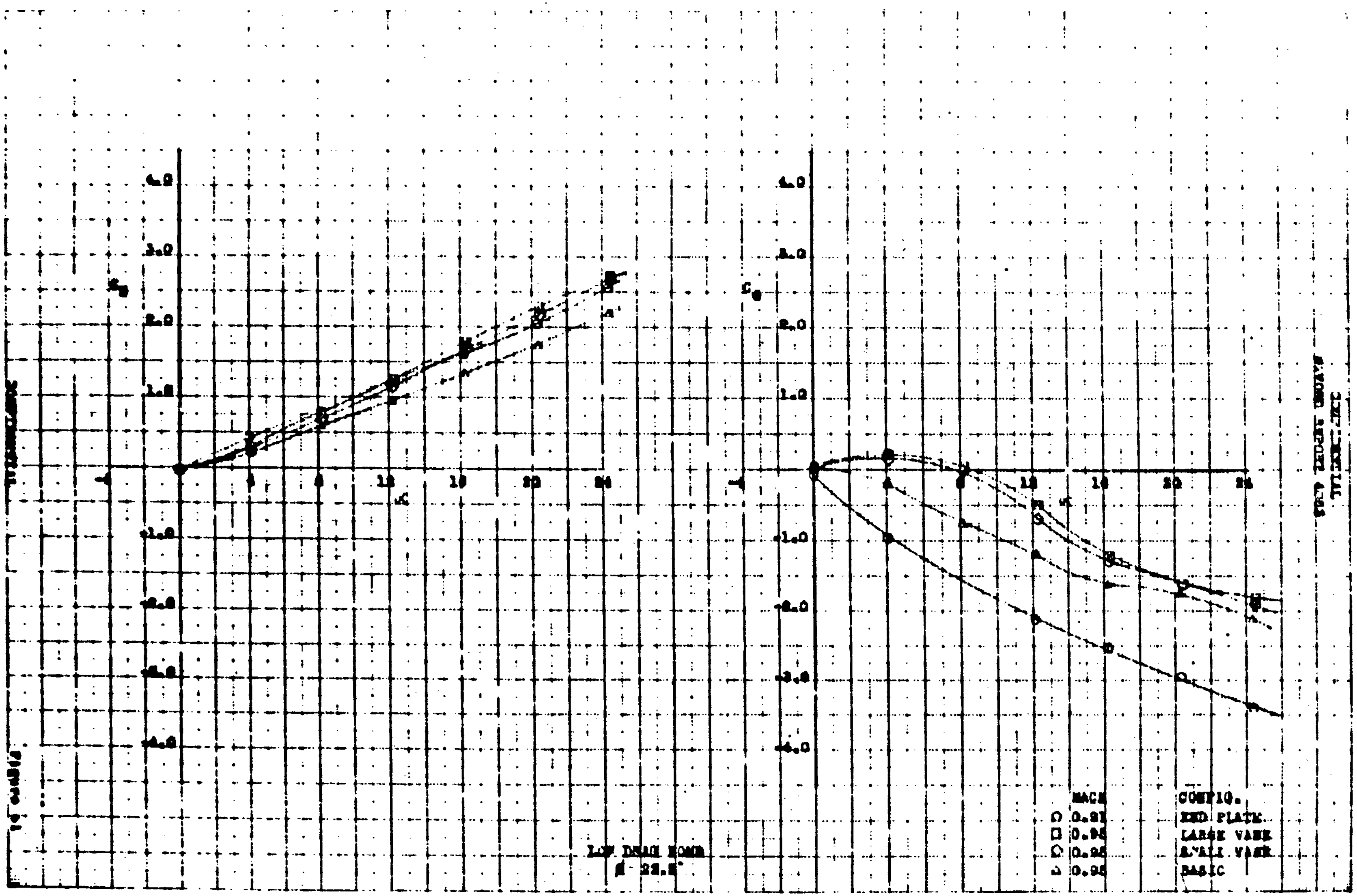
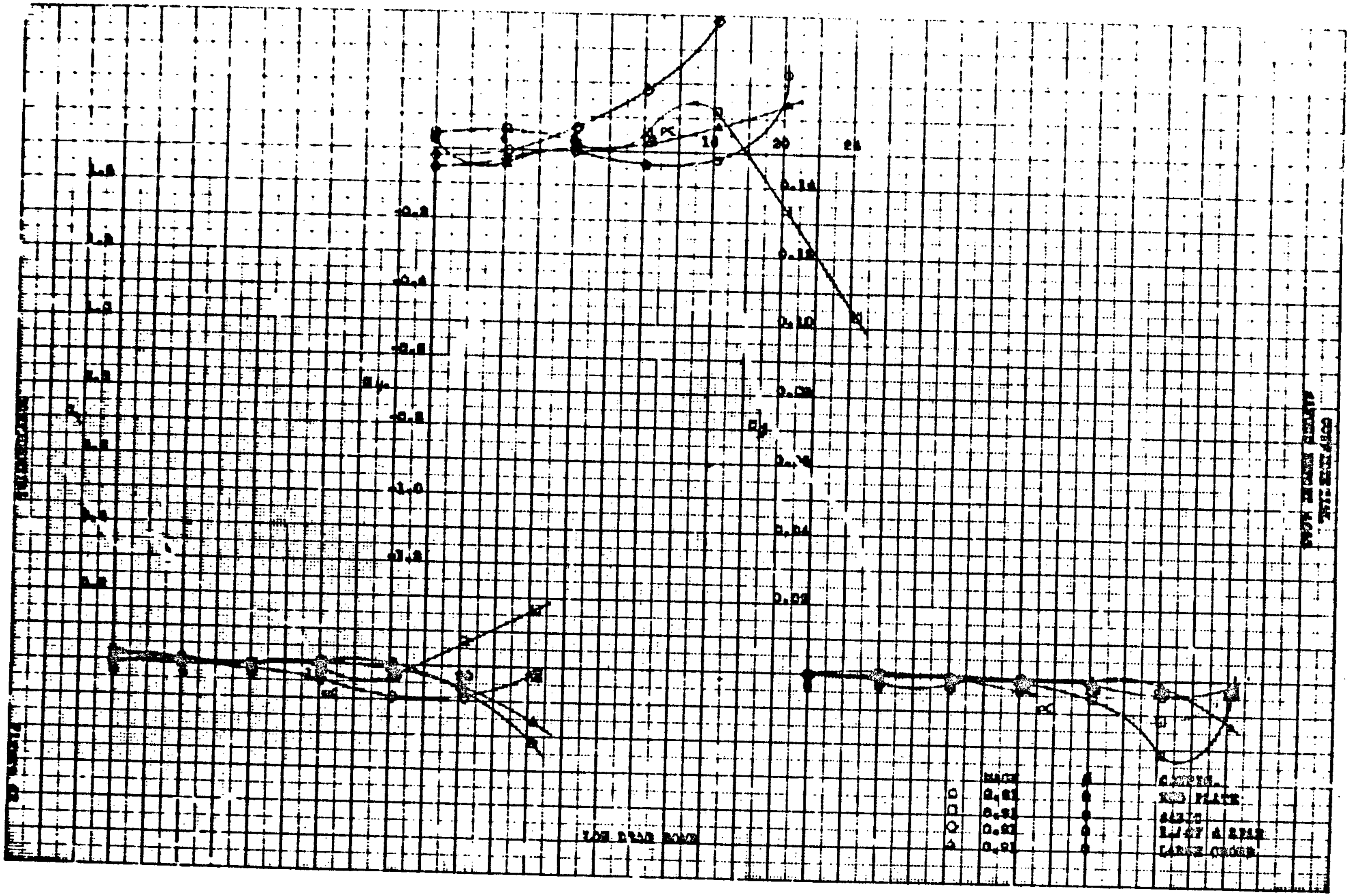
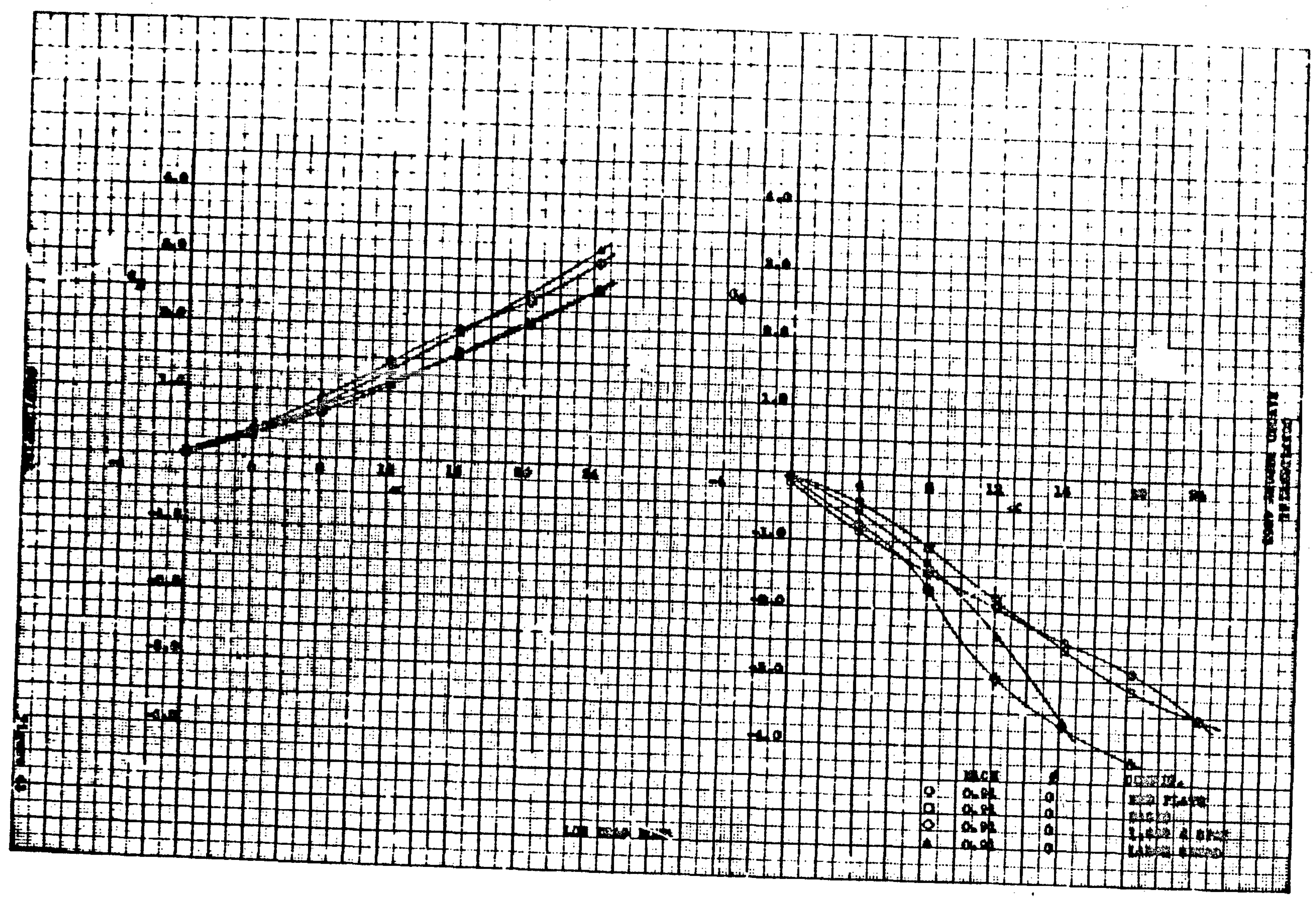
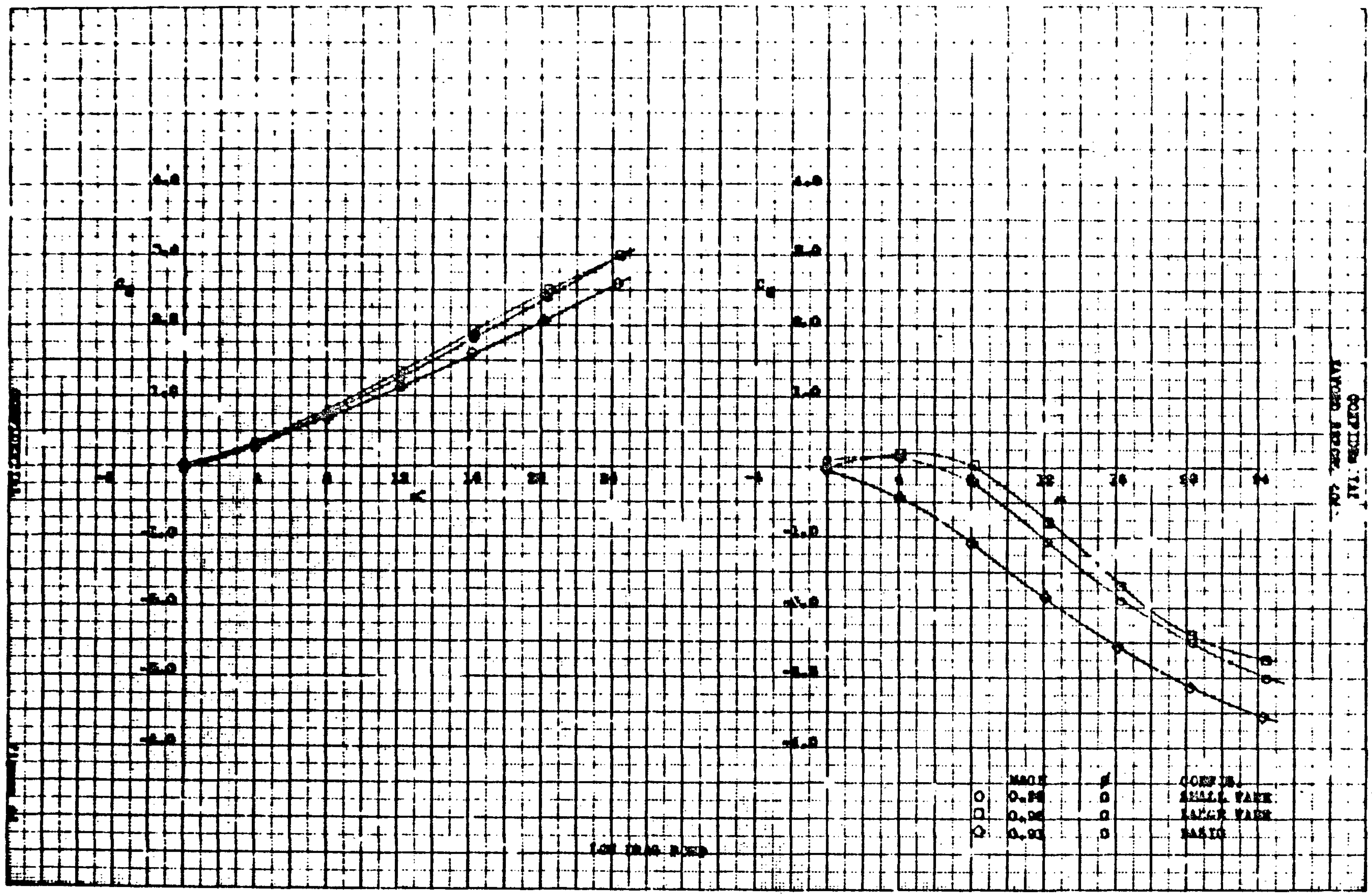

C_N
C_m
α
MACH
CONFIG.
O 0.81 END PLATE
□ 0.95 LARGE VANE
◇ 0.95 SMALL VANE
△ 0.95 BASIC
LOW DRAG BOMB
ϕ 22.5°

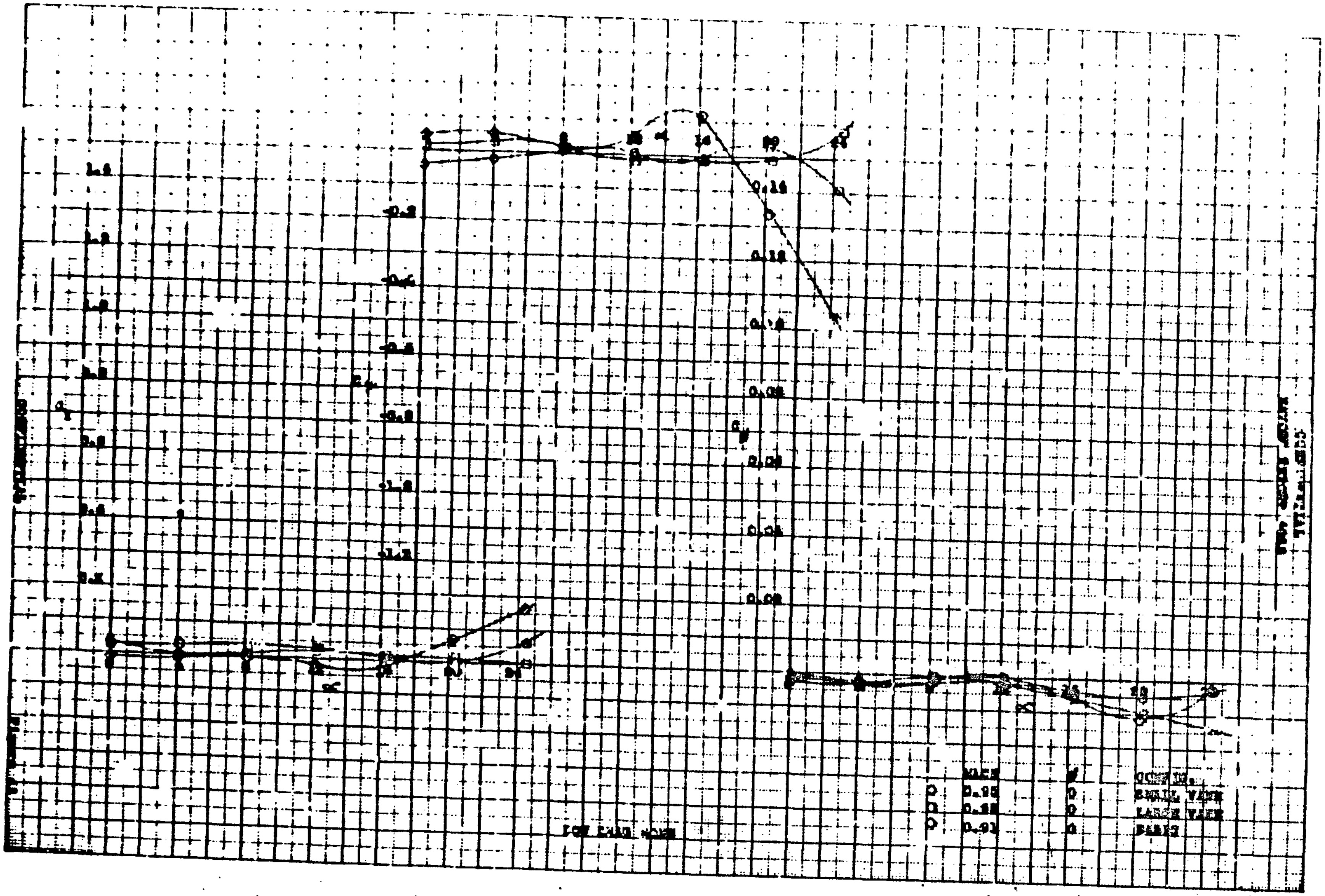
Figure 61

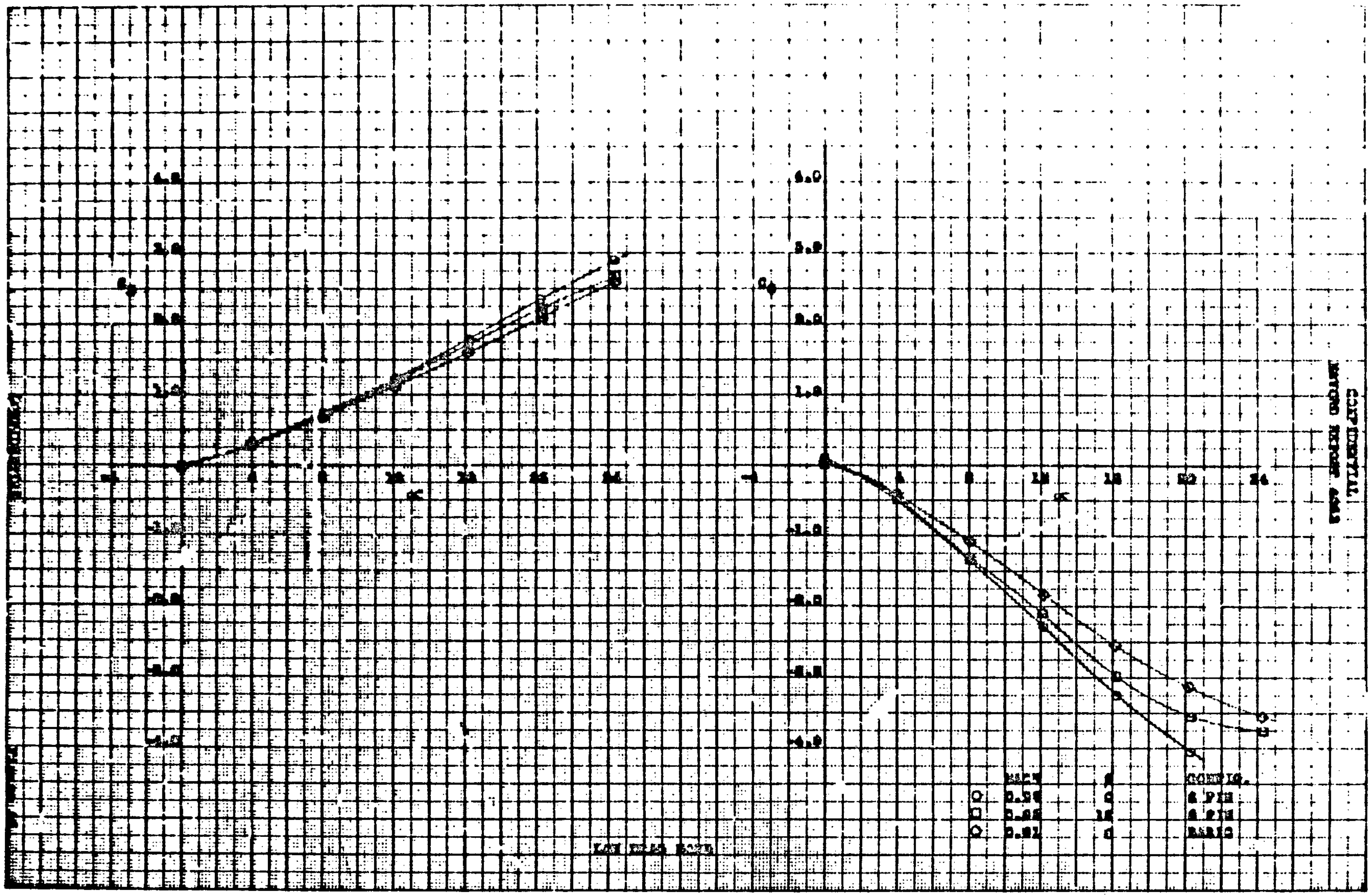

20
25
0.14
0.12
0.10
-0.2
-0.4
-0.6
-0.8
-1.0
MACH
LOW DRAG BODY

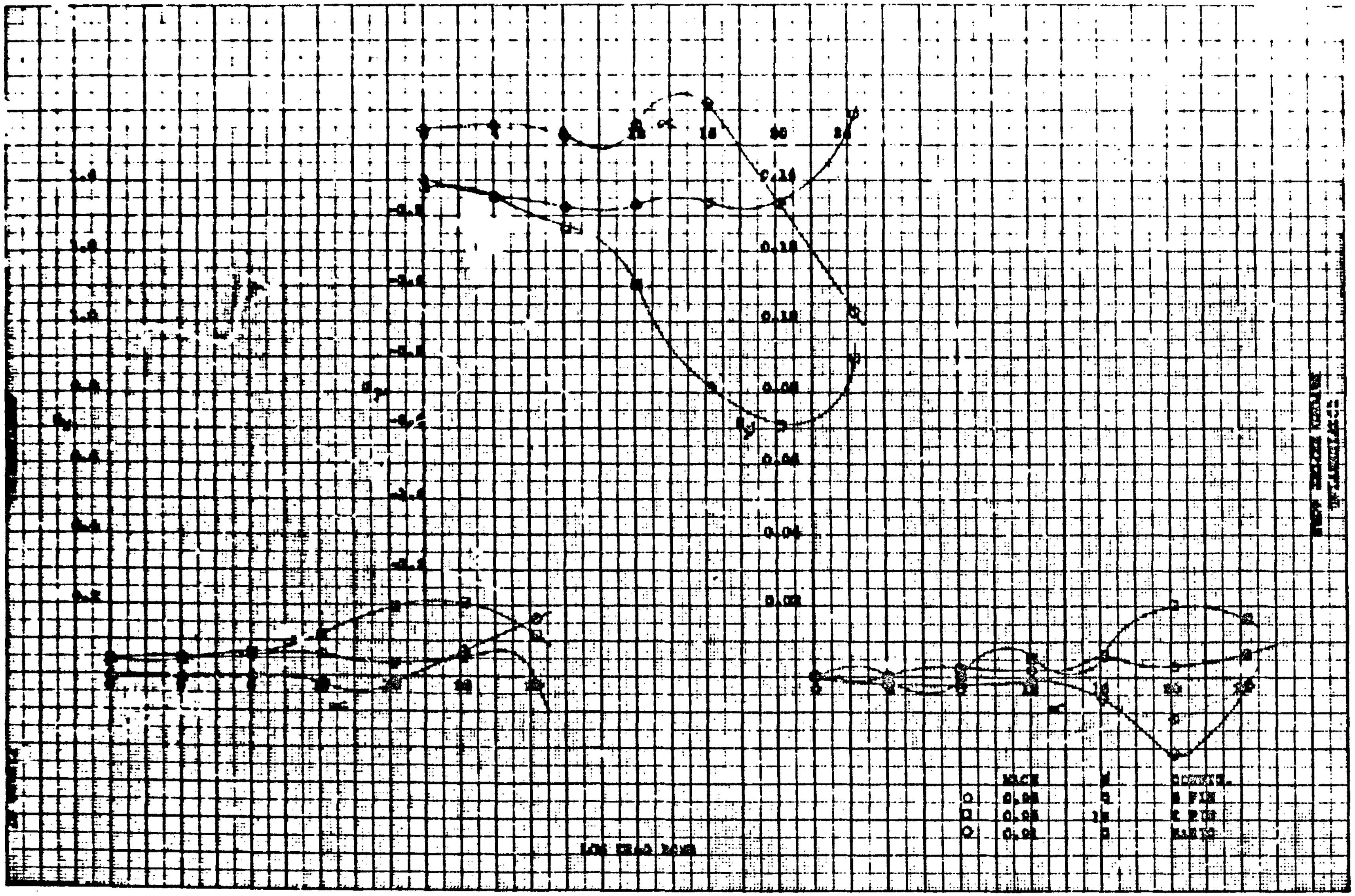

4.0
3.0
2.0
1.0
-1.0
-2.0
-3.0
-4.0
4
8
12
16
20
24
MACH

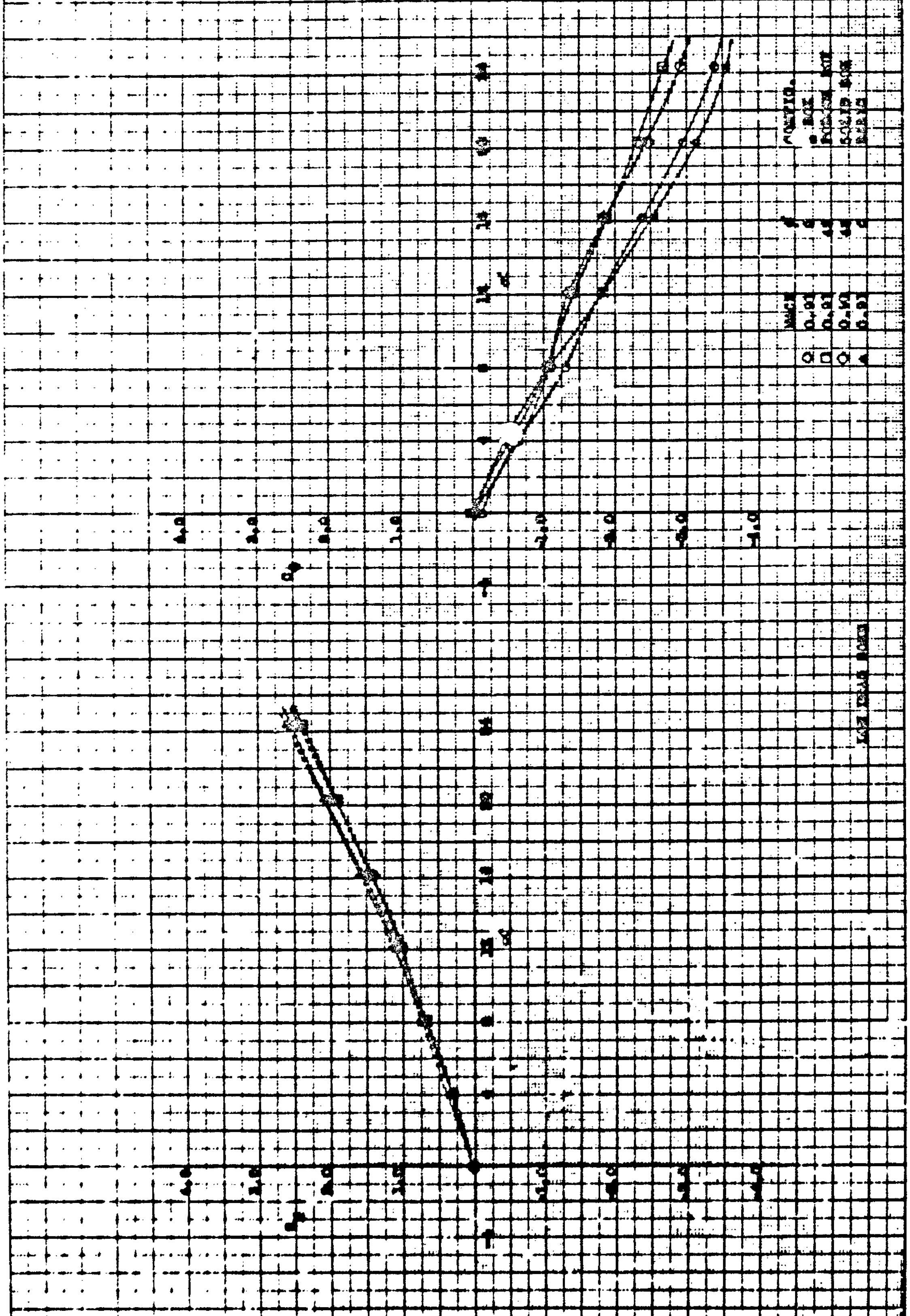


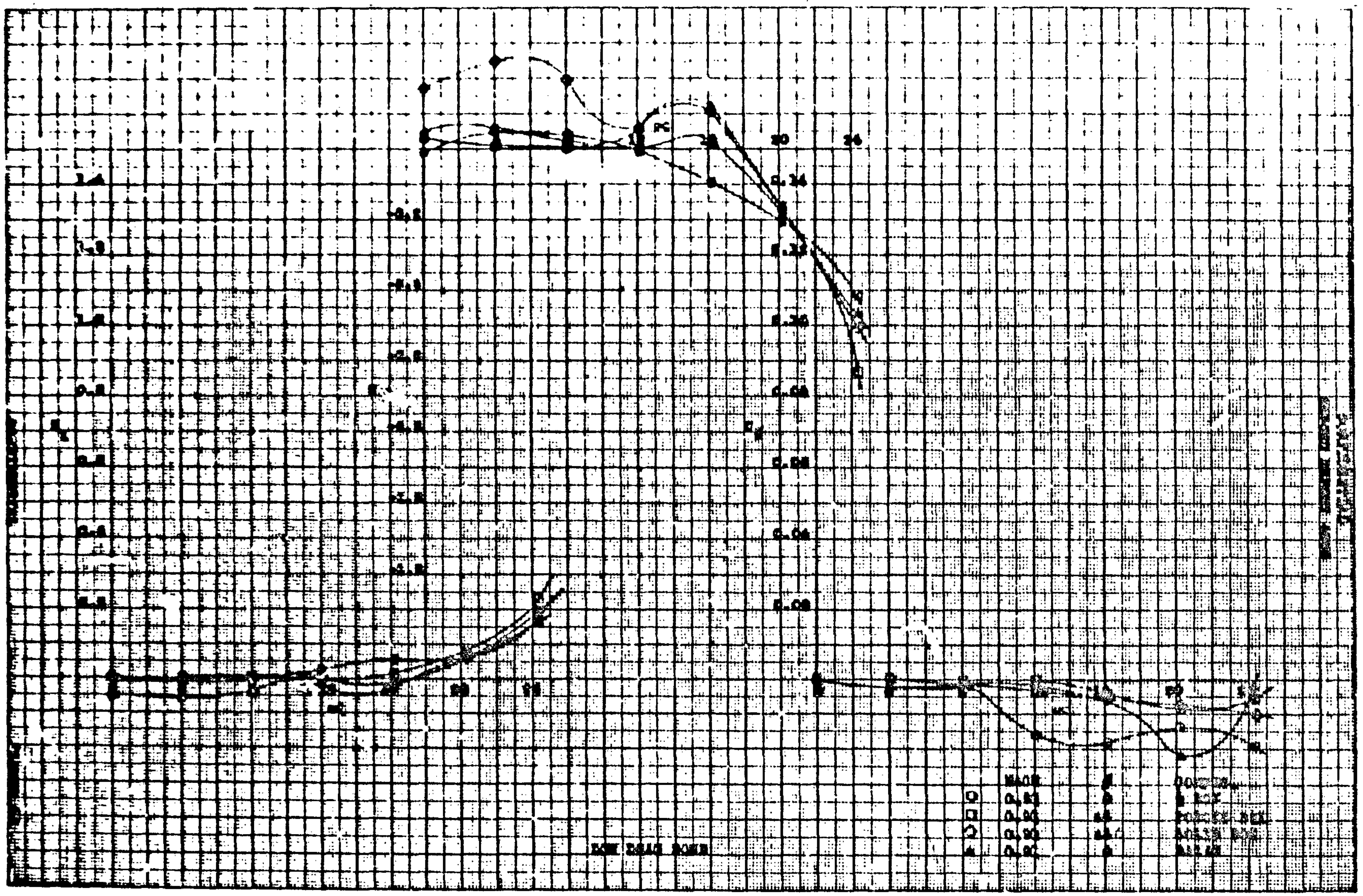
LOW DRAG BOMB
MACH
CONFIG.
SMALL WAKE
LARGE WAKE
BASIC


LOW DRAG WING
MACH
0.95
0.88
0.91
CONFIG.
SMALL VANE
LARGE VANE
BASIC

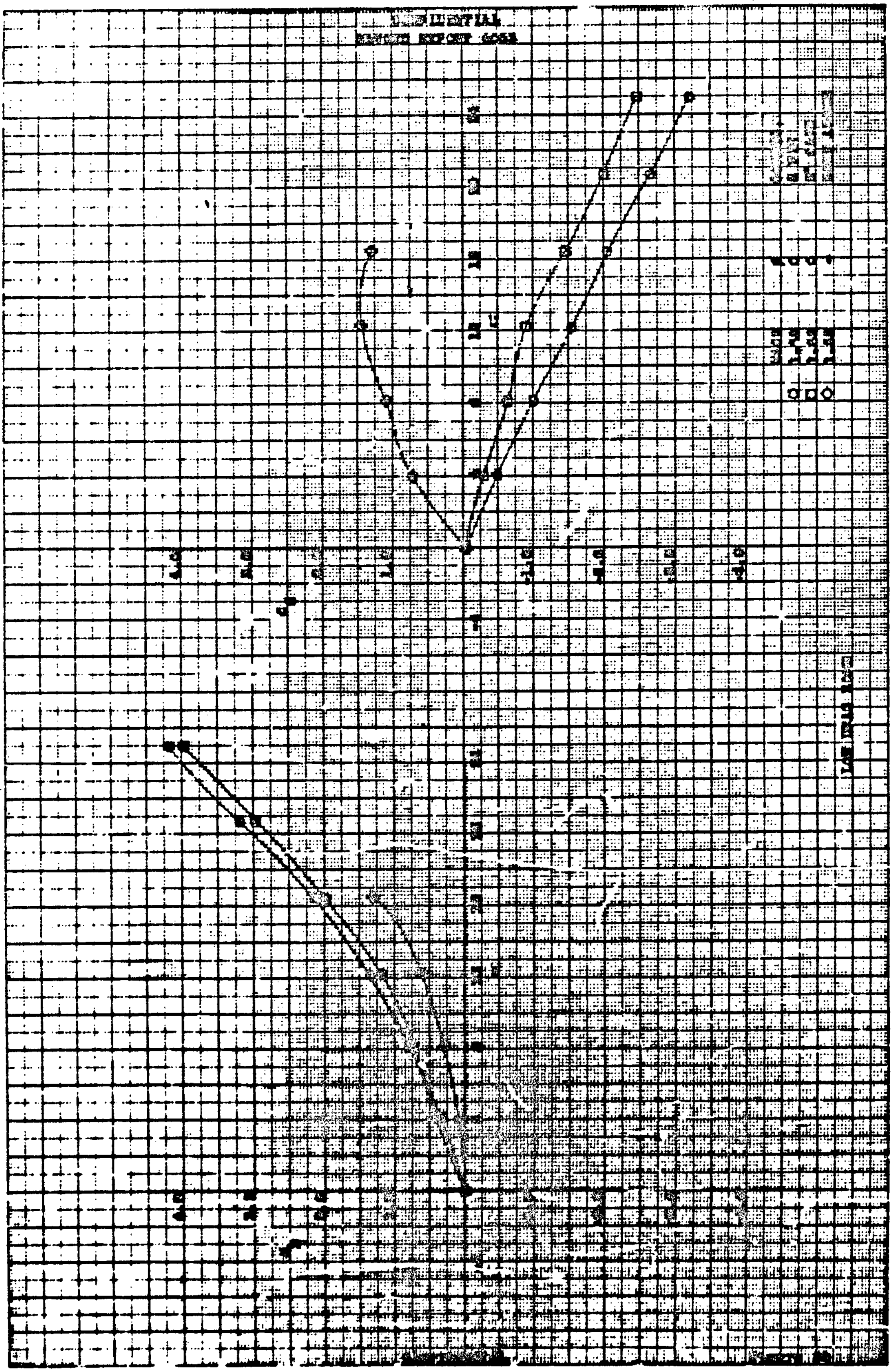

CONFIG.
BASIC

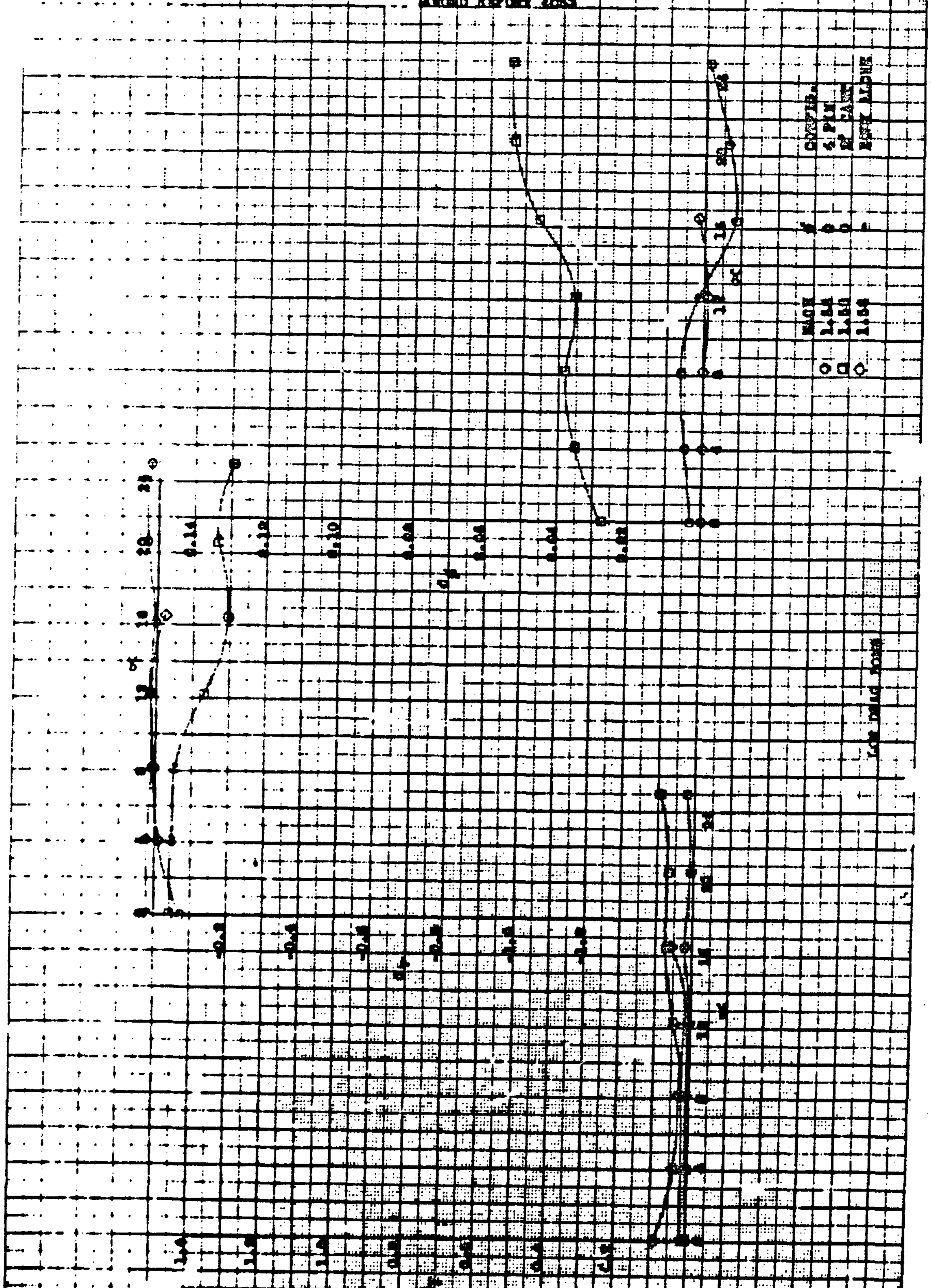

MACH
0.14
0.12
0.10
0.08
0.06
0.04
0.02

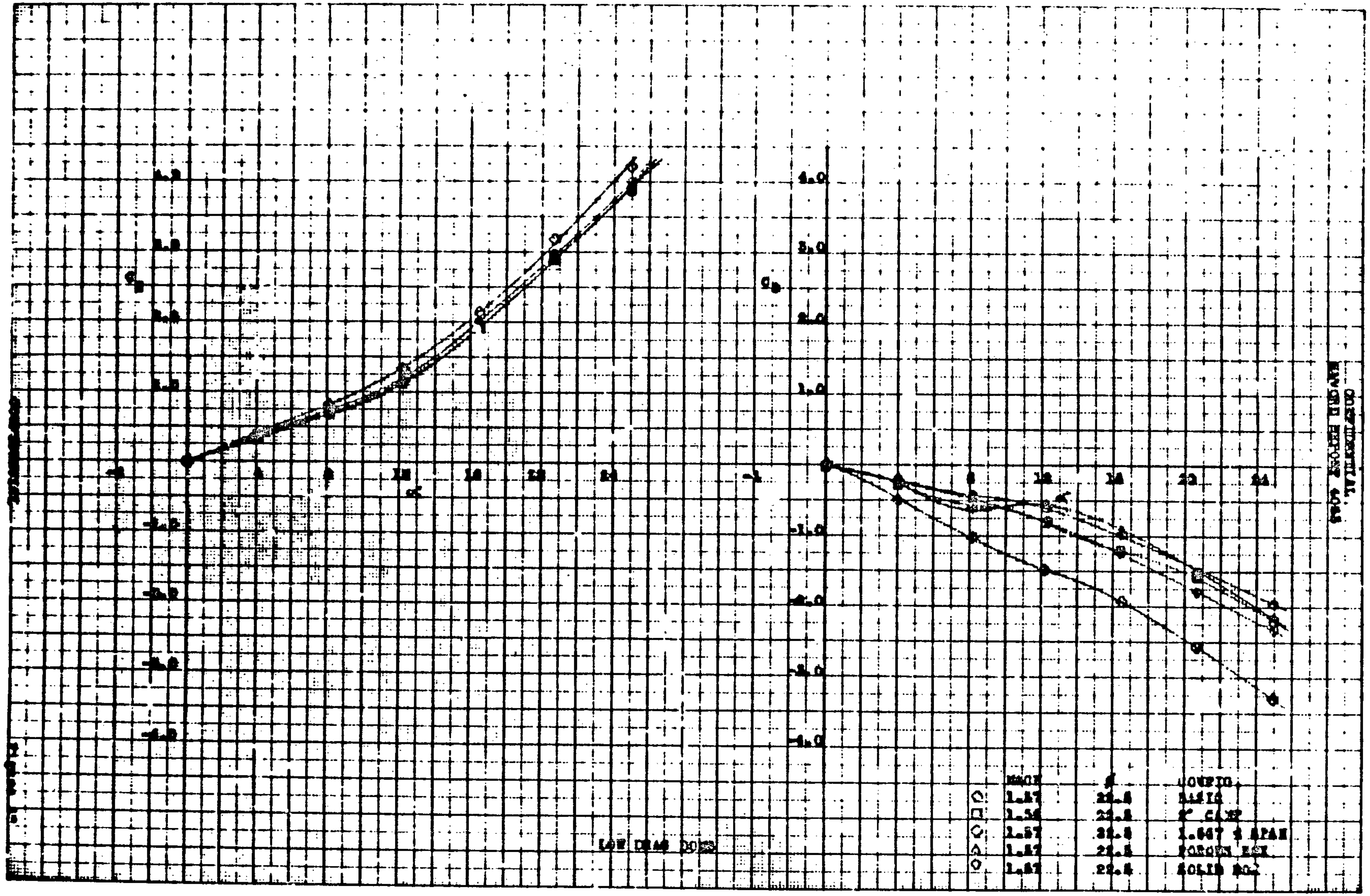




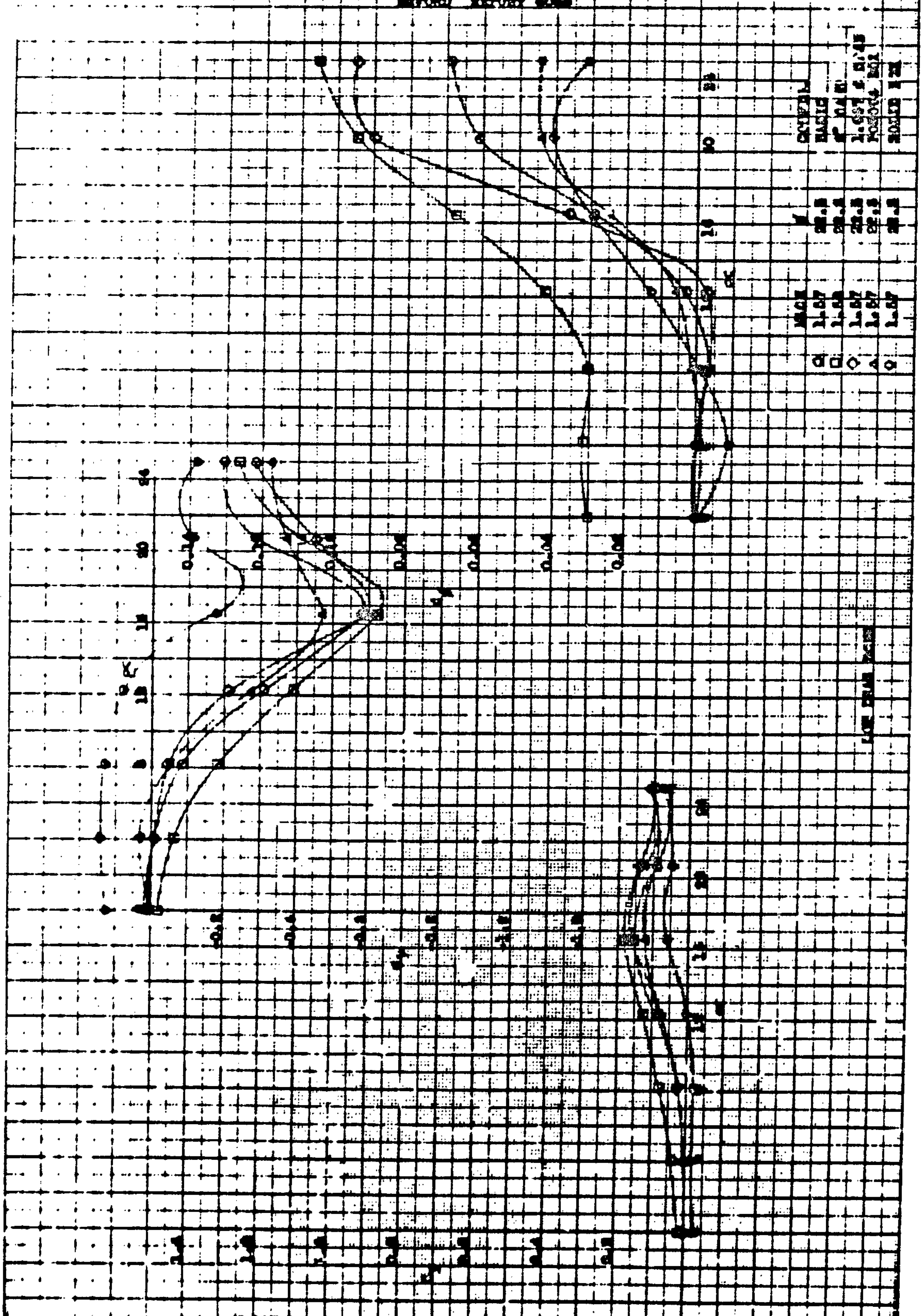
CONFIDENTIAL
RESEARCH REPORT 6063



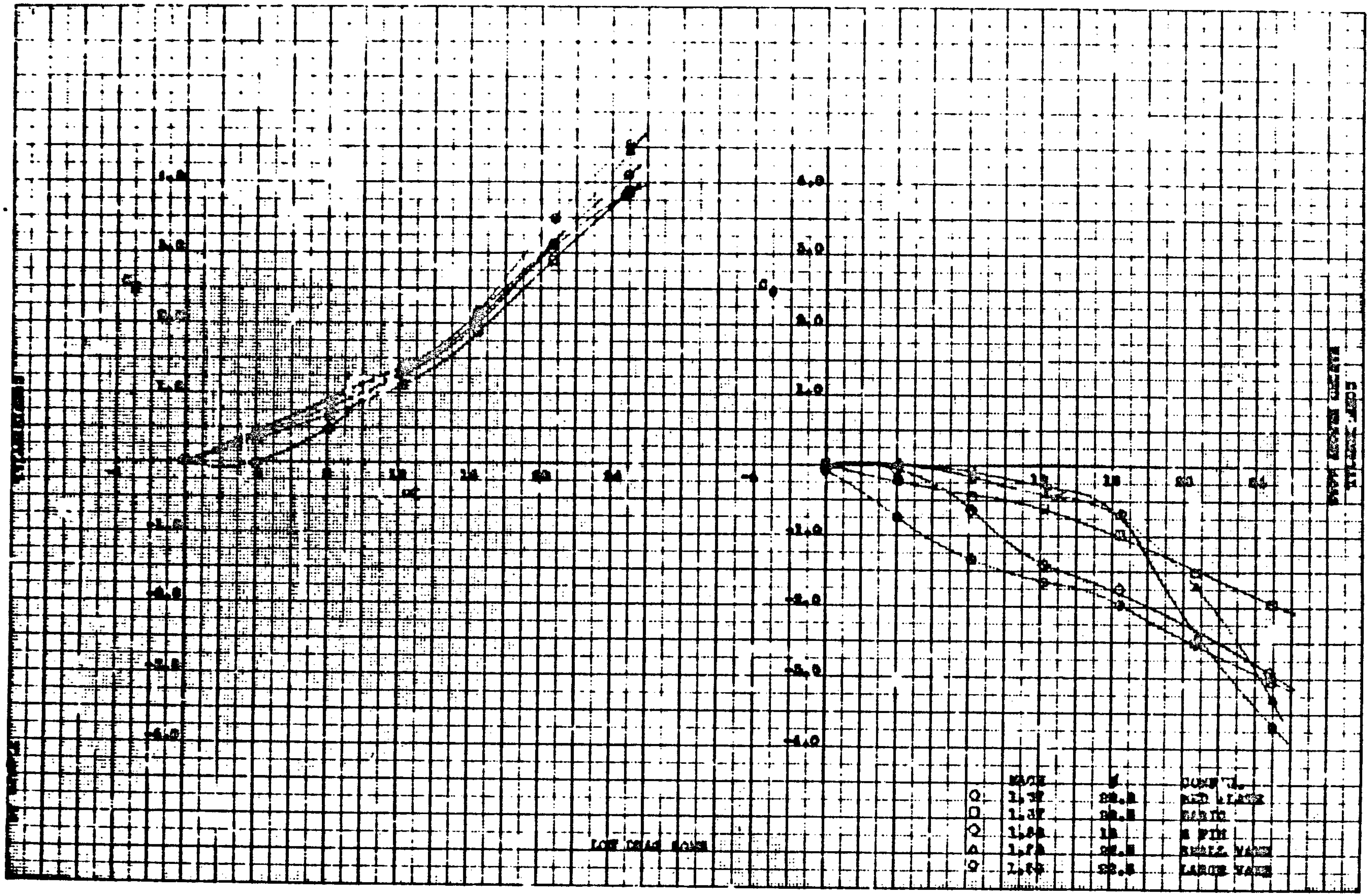


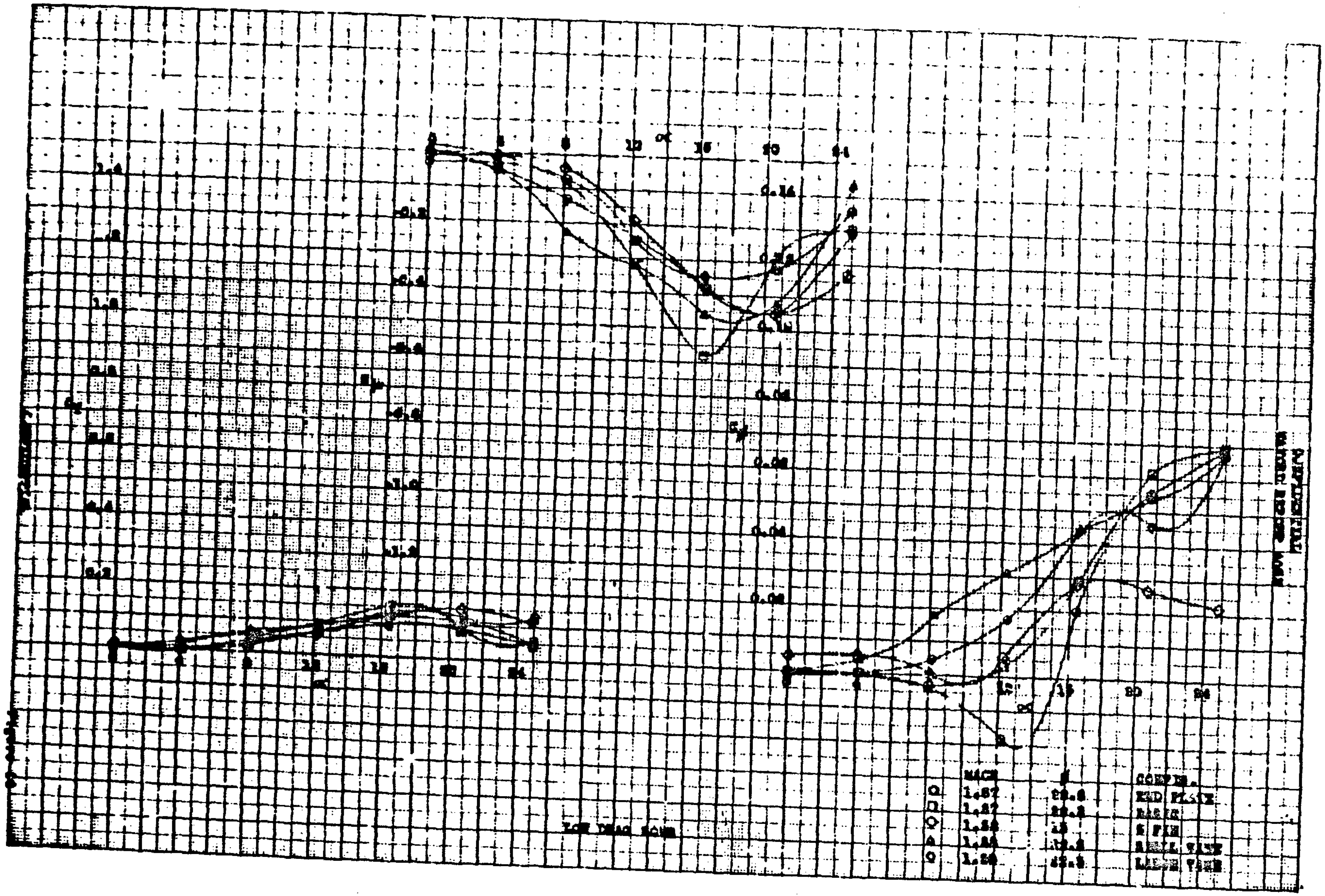

C_N
4.0
3.0
2.0
1.0
-1.0
-2.0
-3.0
-4.0
-8
4
8
12
16
20
24
α
C_m
4.0
3.0
2.0
1.0
-1.0
-2.0
-3.0
-4.0
-4
8
12
16
22
24
MACH
1.57
1.56
1.57
1.57
1.57
ϕ
22.5
22.5
22.5
22.5
22.5
CONFIG.
BASIC
2" CAMP
1.667 X SPAN
FORGED REX
SOLID BO.
LOW DRAG BODY

CONFIDENTIAL
NAVORD REPORT 4068

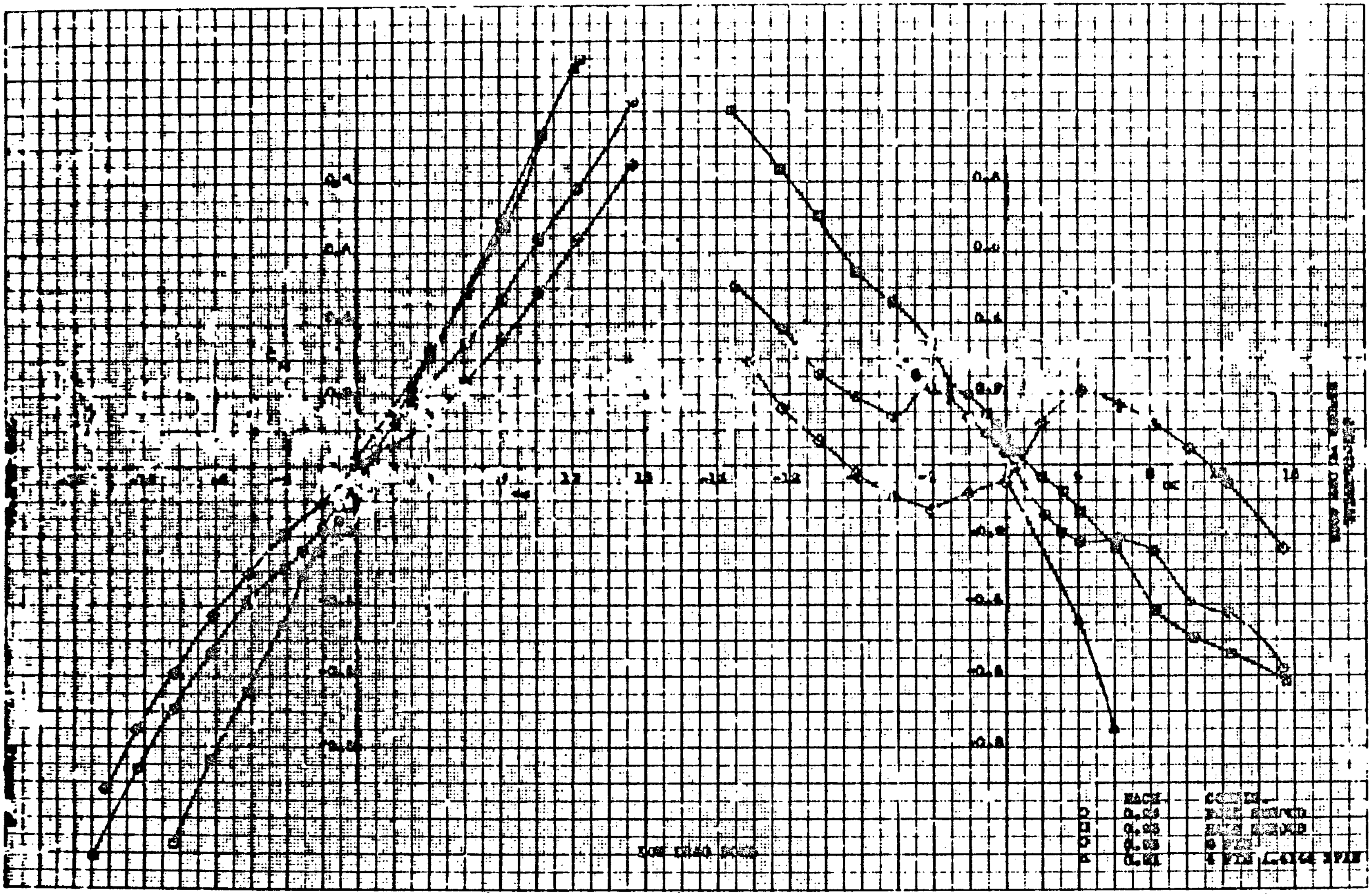


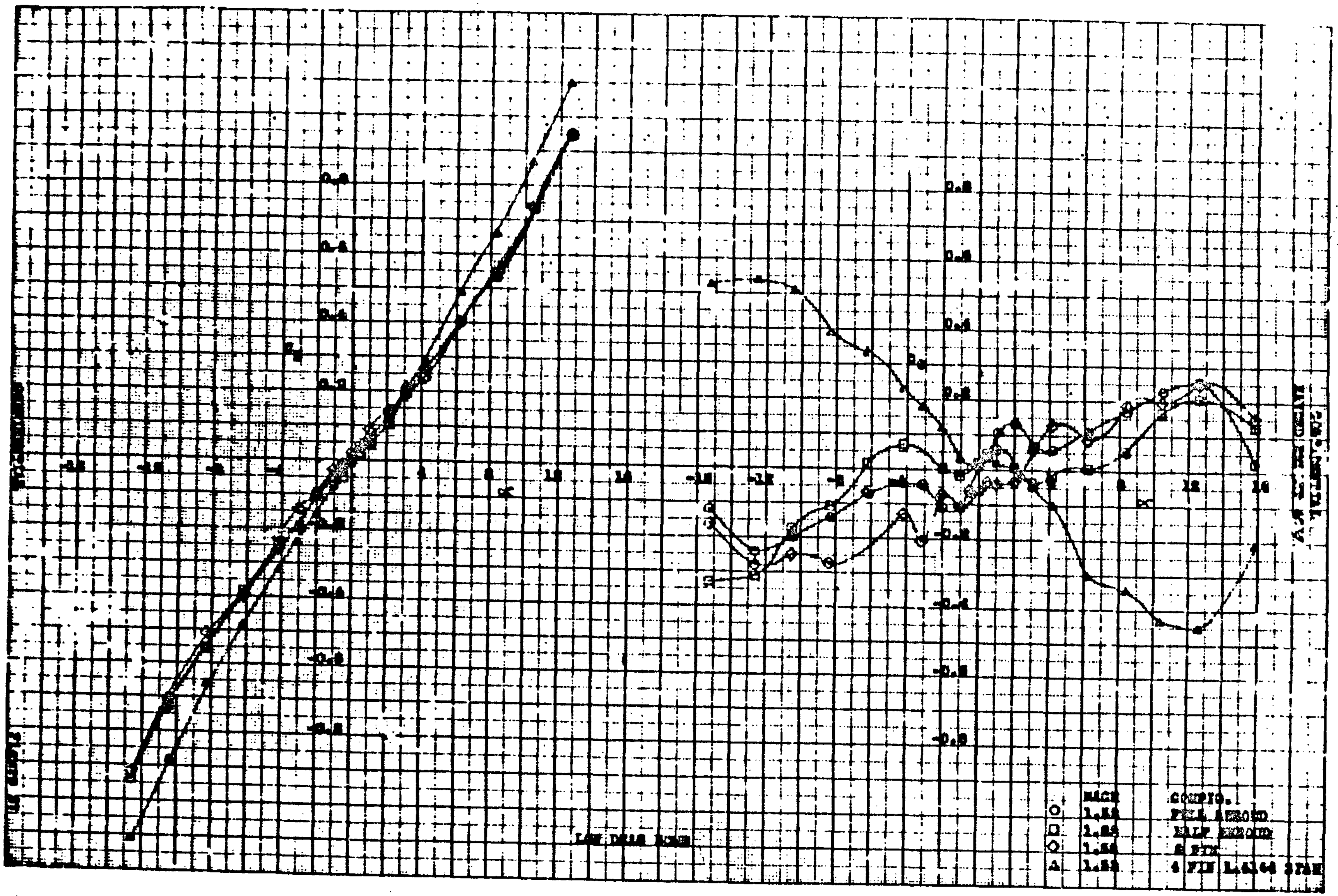
CONFIDENTIAL

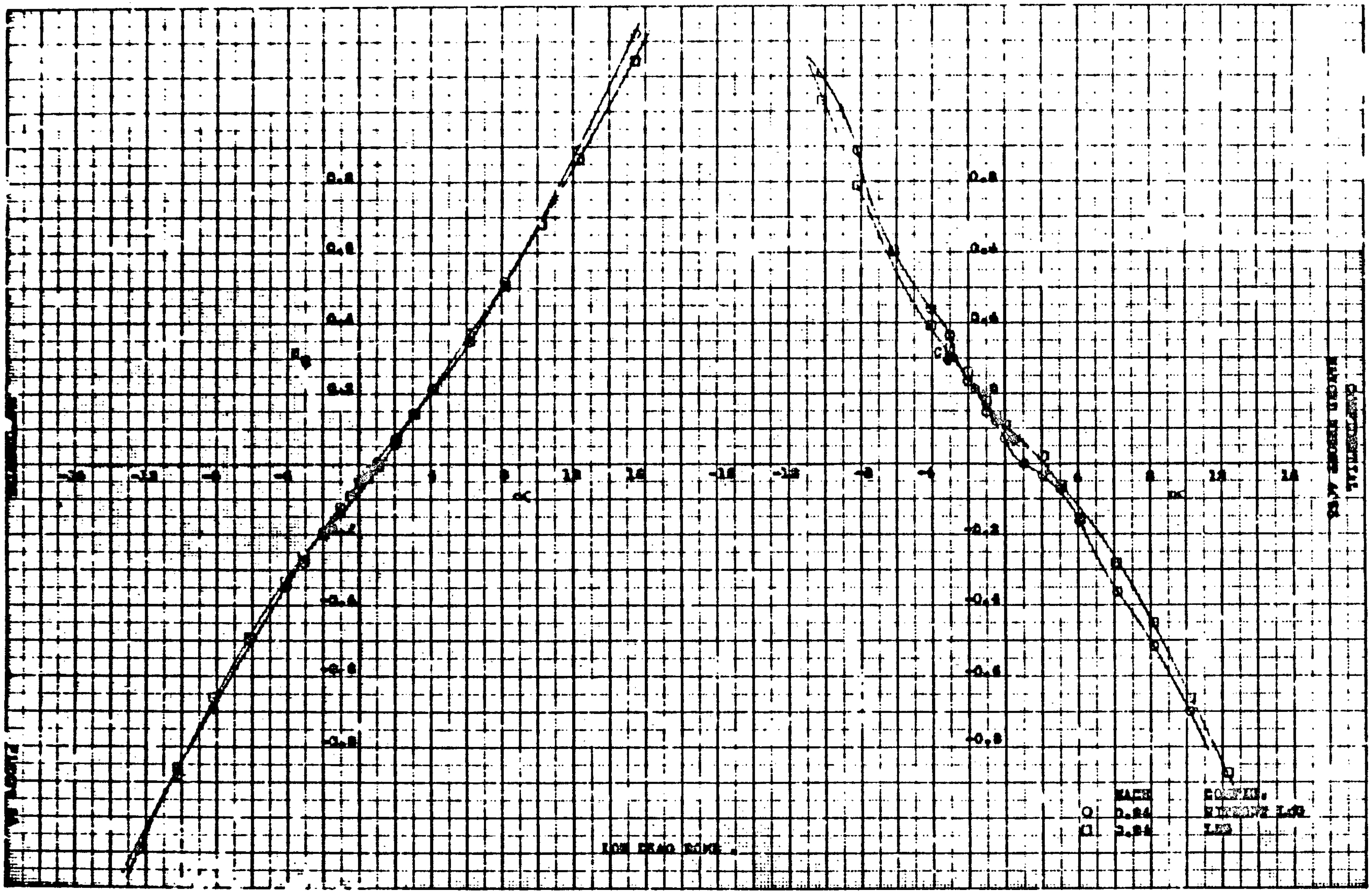

LOW DRAG NOSE
MACH
CONFIDENTIAL



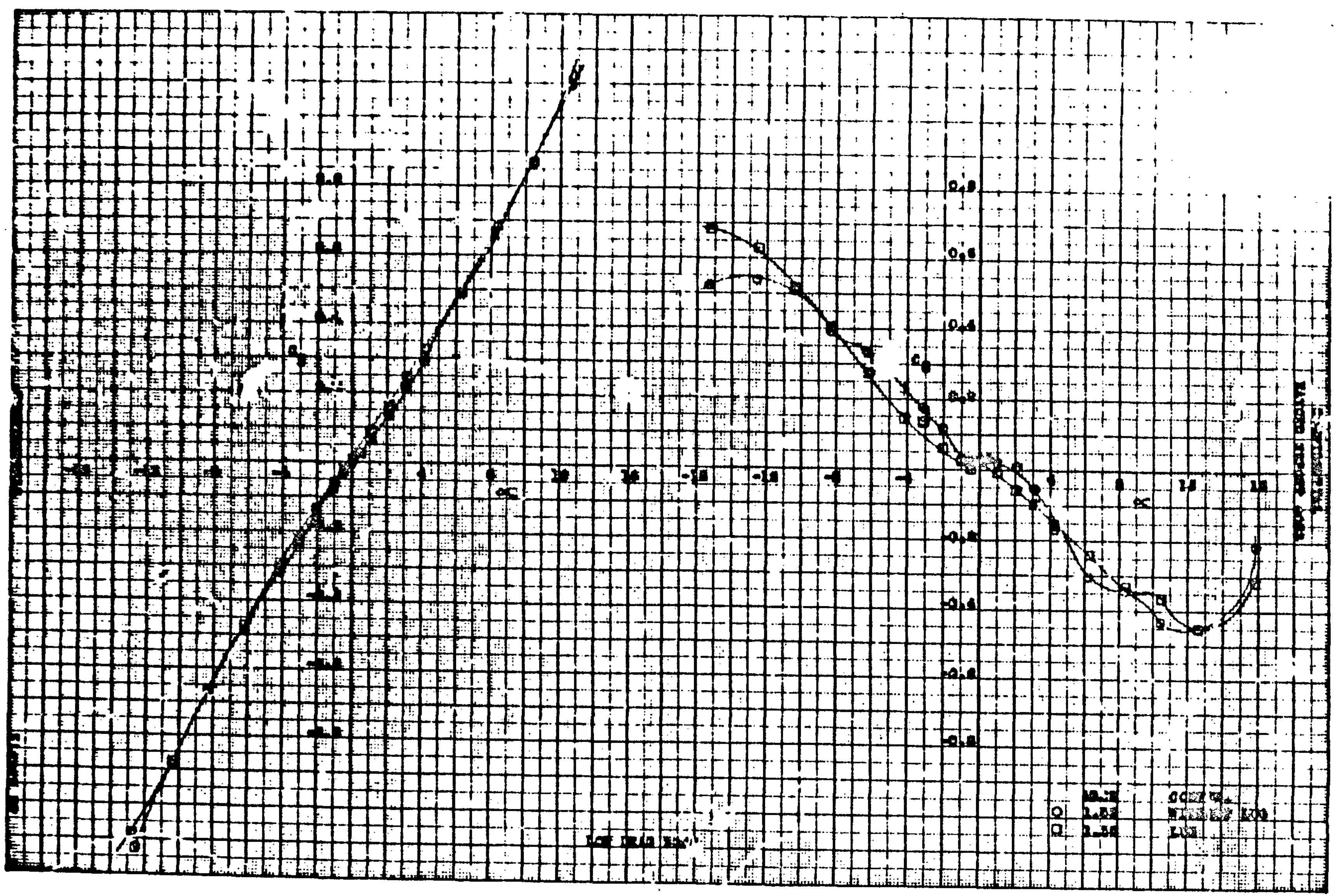
MACH
CONFIG.
END PLATE
BASIC
LOW DRAG BOMB

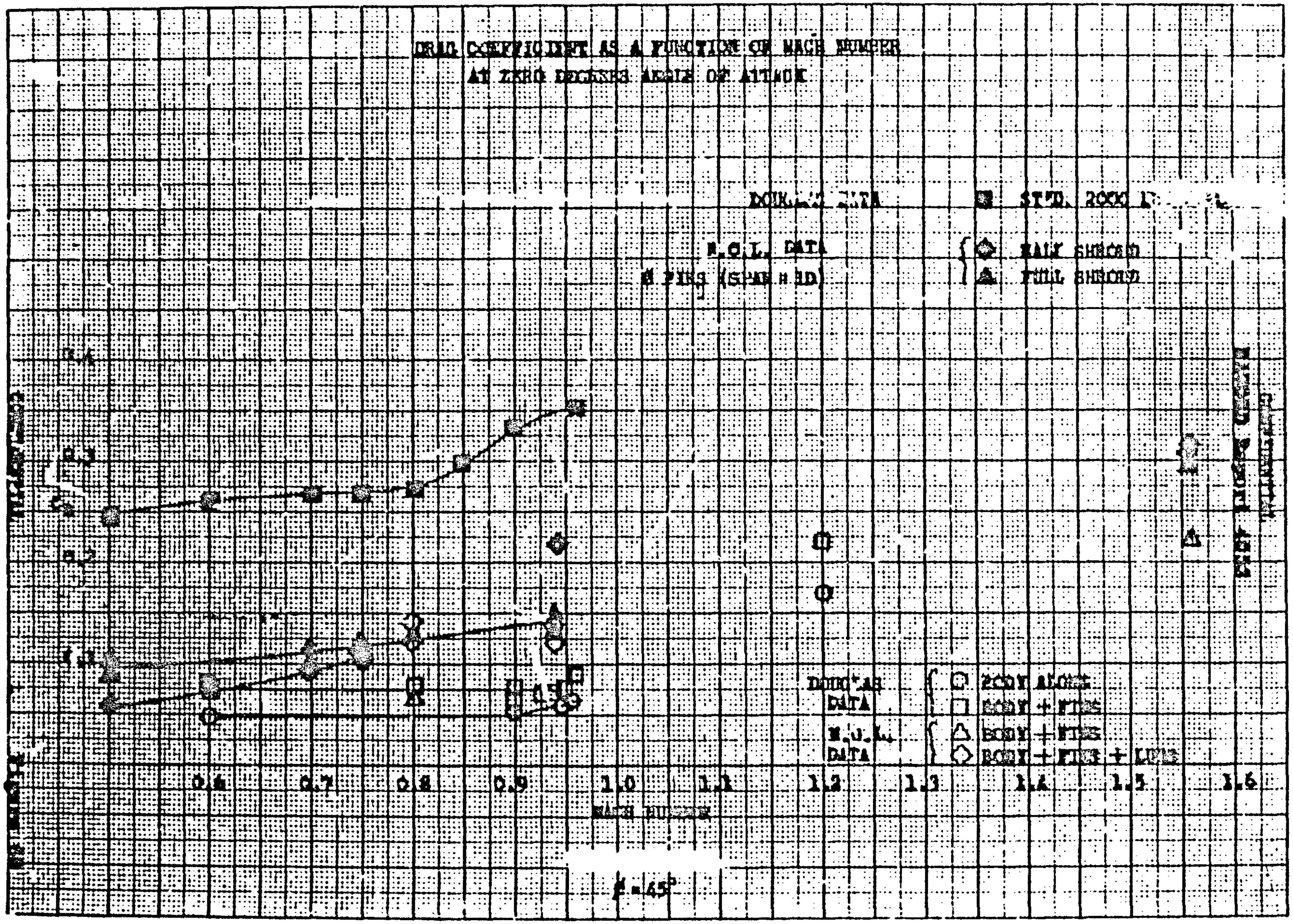

MACH


MACH
CONFIG.

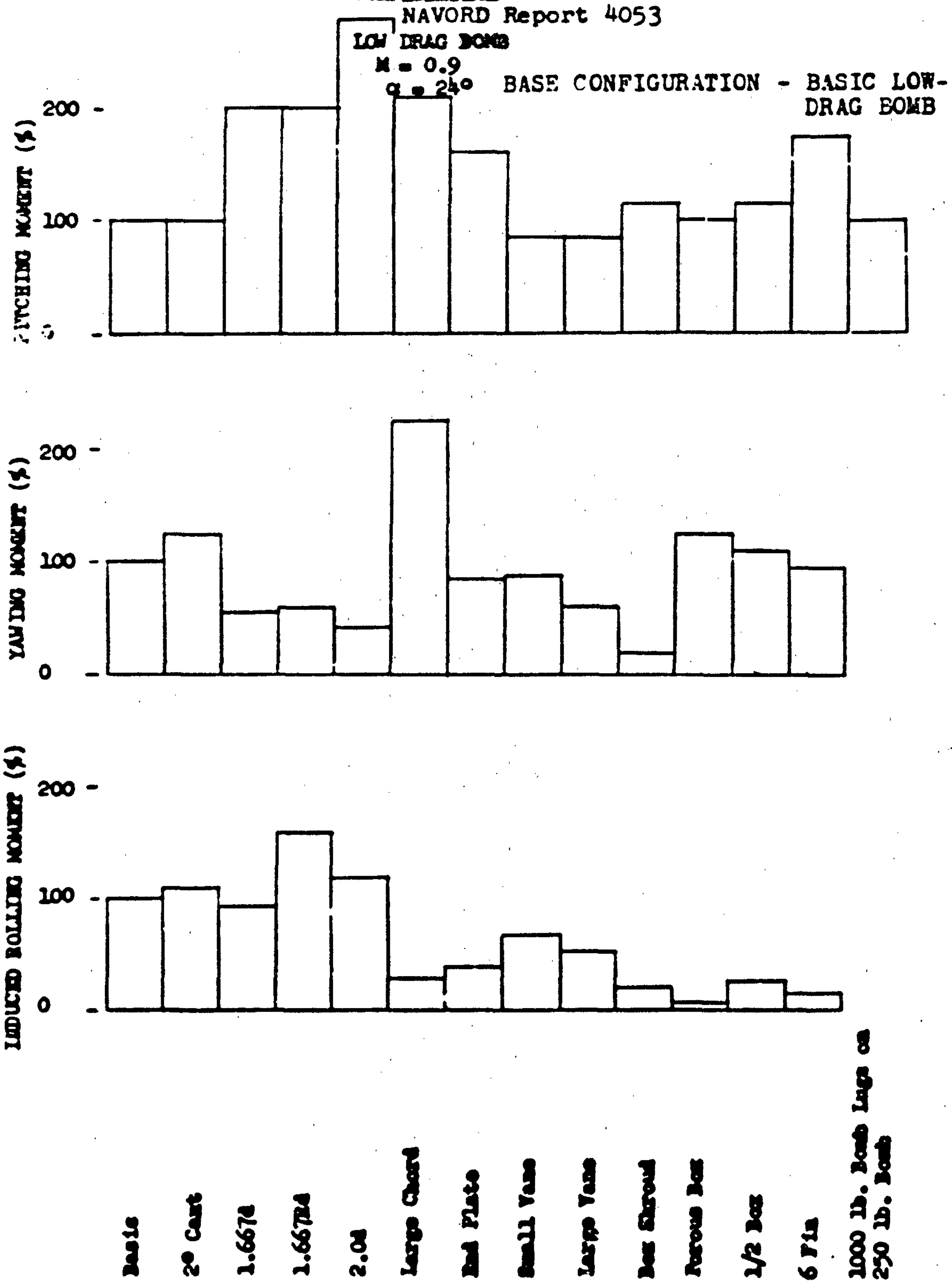


0.8
0.6
0.4
0.2
-0.2
-0.4
-0.6
-0.8
-16
-12
-8
-4
0
4
8
12
16
LOW DRAG RANGE
MACH




DRAG COEFFICIENT AS A FUNCTION OF MACH NUMBER
AT ZERO DEGREES ANGLE OF ATTACK
N.O.L. DATA
HALF SHROUD
FULL SHROUD
DOUGLAS DATA
BODY ALONE
BODY + FINS
N.O.L. DATA
BODY + FINS
BODY + FINS + LUGS
0.4
0.3
0.2
0.1
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
1.6
MACH NUMBER
CONFIDENTIAL

CONFIDENTIAL
NAVORD Report 4053



CONFIDENTIAL

Fig. 61

LOW DRAG BOMB
$M = 1.57$
$\alpha = 24°$ BASE CONFIGURATION - BASIC LOW-DRAG BOMB

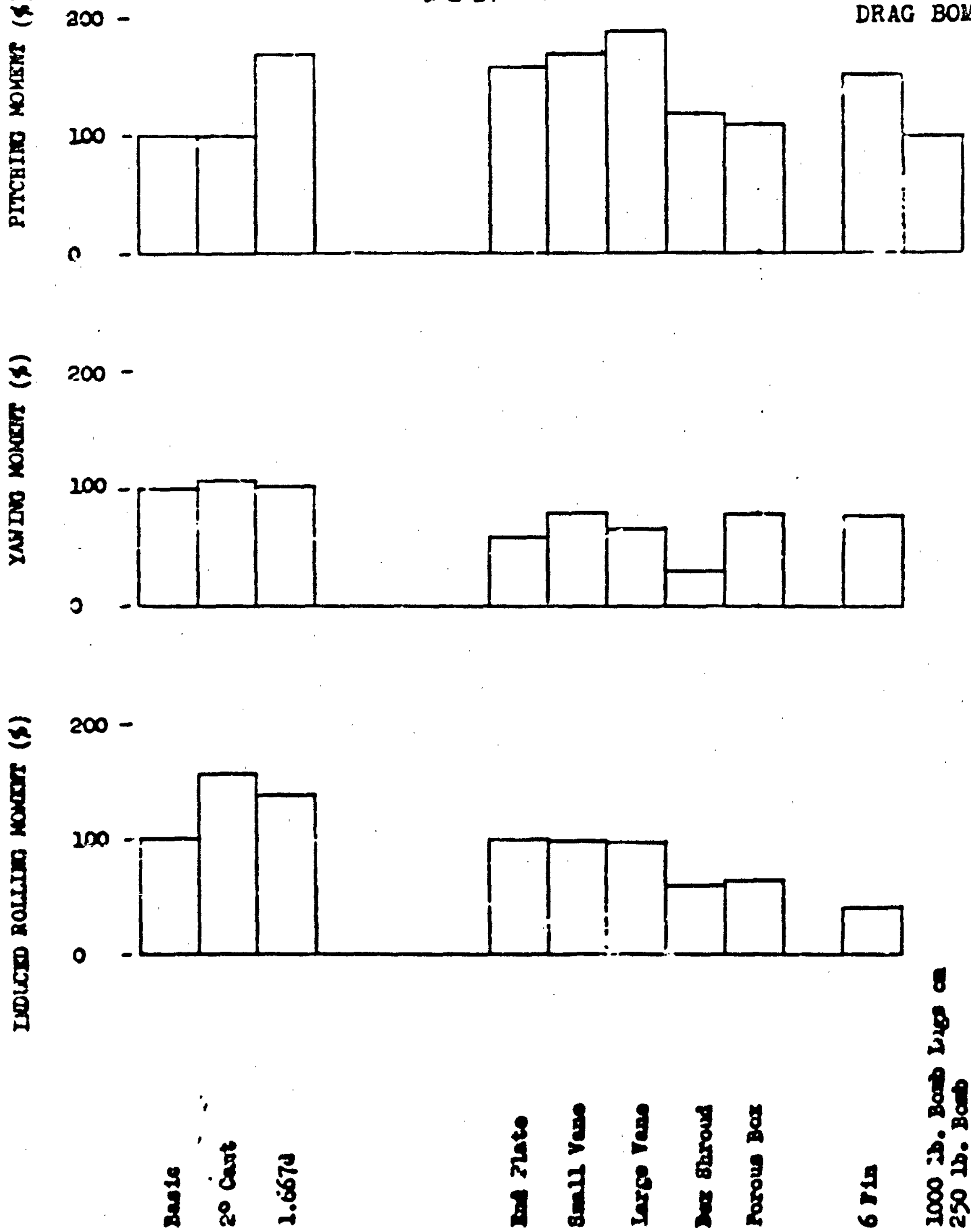
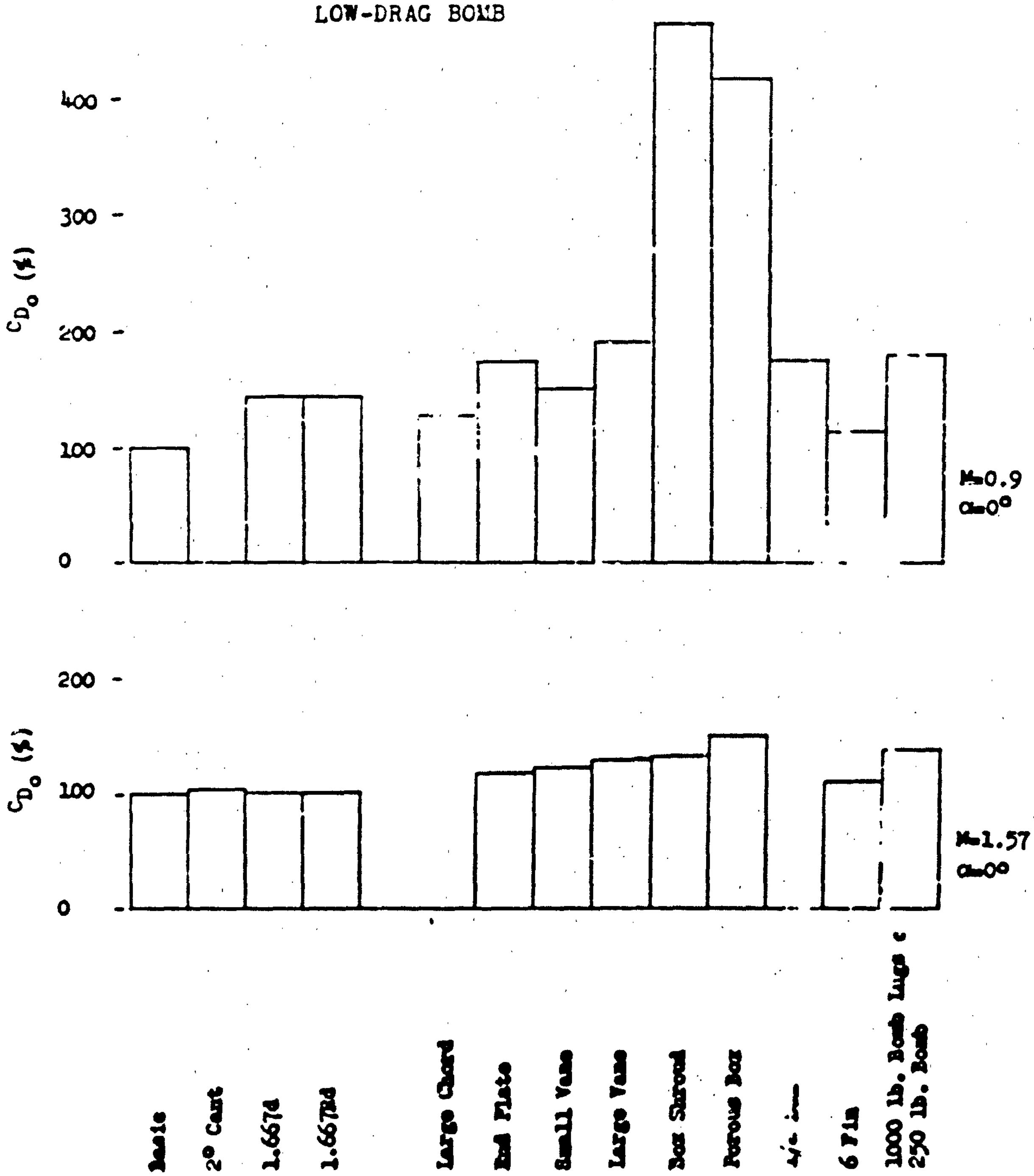


Fig. 62

[redacted]

BASE CONFIGURATION - BASIC LOW-DRAG BOMB



[redacted]

Fig. 3